TREATMENT TECHNOLOGIES

FOR

CONTAMINATED GROUNDWATER

(A LITERATURE REVIEW)

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Ontario

Ministry of
Environment
and Energy

TREATMENT TECHNOLOGIES

FOR CONTAMINATED GROUNDWATER

(A LITERATURE REVIEW)

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ACRONYMS USED IN THE REPORT

BTEX	benzene, toluene, ethylbenzene, xylene
DNAPL	dense non-aqueous phase liquids
DCE	dichloroethylene
EPA	Environmental Protection Agency (U.S.)
LNAPL	light non-aqueous phase liquids
MOEE	Ministry of Environment and Energy (Ontario)
PAH	polynuclear aromatic hydrocarbons
PCB	polychlorinated biphenyl
PCE	perchloroethylene
ppb	parts per billion
ppm	parts per million
TCA	trichloroethane
TCE	trichloroethylene
UV	ultra violet
ug/L	microgram per litre
VOC	volatile organic compound.

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1.0 INTRODUCTION

Groundwater contamination caused by industry, agriculture and municipal activities presents a variety of risks which may affect ultimate end-use of the resource including household, farming and industrial applications. Any of these potential risks depending upon the nature and extent of the contamination, may provide a reason for groundwater treatment. It is important therefore, to address the problem of subsurface groundwater contamination with suitable treatment methods.

The primary purpose of this report is to provide a summary of the various groundwater treatment technologies that have been developed and commercially available, are in a state of development but still need testing and verification, or alternative technologies that are in the process of being tested. Due to the rapid advance of contaminated groundwater treatment science, the catalogue of technologies included in this report should not be viewed as exhaustive. The focus in the literature reviewed is largely on groundwater contamination by hazardous organic contaminants and especially, non-aqueous phase liquids.

Treatment, in this report, is the application of a technology to a specific medium for the separation or destruction of a compound. We treat water, air or soil media. **Remediation** on the other hand, is the cleaning of an environment. We remediate an industrial site or an aquifer, but we treat groundwater.

2.0 BACKGROUND

In the early 1980s it became evident in North America and Europe that aquifers had been impacted by a variety of solvents, pesticides, road maintenance activities such as road de-icing, dust control, and other chemicals e.g nitrates, sulphate salts, metals and organic chemicals of industrial origin. Of the many organic chemical contaminants detected in groundwater, chlorinated organic solvents are by far the most frequently discussed in the literature. Groundwater contamination by organic chemicals from sources such as waste disposal facilities, chemical spills and leaking underground storage tanks has become a significant issue in many parts of the modern world.

The potential for extensive contamination of groundwater by the Non-Aqueous Phase Liquids (NAPLs) and particularly the Dense Non-Aqueous Phase Liquids (DNAPLs) is high. Presently, this problem is compounded by the lack of reliable quantitative information concerning the extent of contamination.

Organic chemicals such as trichloroethylene (TCE), trichloroethane (TCA), perchloroethylene (PCE), methylene chloride, some pesticides, coal tar and creosotes are DNAPL chemicals. These chemicals have been extensively used over the years in many industrial activities as dense organic solvents. DNAPL chemicals are characterised by high densities and low viscosities. Once released into the subsurface (undiluted), these chemicals are able to sink through the unsaturated and saturated zones. By their tendency and capability to migrate vertically into the subsurface, these chemicals are markedly different from petroleum hydrocarbons which float on groundwater due to their lower densities. This

characteristic behaviour makes DNAPLs difficult to study and remediate unlike any other organics. However, extensive laboratory research work augmented by detailed field tests are being conducted, notably at the University of Waterloo, in Canada and in many other countries, to determine fully the subsurface transport characteristics and appropriate remedial methods for these ubiquitous chemicals.

3.0 TECHNOLOGY SELECTION AND SUITABILITY

3.1 Criteria for Technology Selection

The key to choosing the right technology or combination of techniques is a thorough site characterization and feasibility study based on the technical, economic, and regulatory issues peculiar to the site. It is also critical to consider the "fate and transport" of contaminants.

Depending on the technologies being considered and the site, essential criteria considered for the selection of groundwater treatment technologies may include:

- concentrations of contaminants in the soil and /or groundwater;
- required clean-up levels or final concentration;
- amount of groundwater to be treated;
- groundwater properties, such as flow rate, direction, hydraulic conductivity, pH, temperature, dissolved oxygen content and oxidation/reduction potential;
- depth to groundwater and relative depth of contamination;
- physical and chemical properties of the contaminants e.g specific gravity, solubility in water or other solvents;
- waste type and toxicity;
- public sensitivity.

The above criteria are inter-related and should be considered as such before a final selection of a particular technology can be made.

3.2 Technology Suitability

During the first phase of the assessment, a suitable groundwater treatment technology is considered. This is a measure of the technology's ability to fully or partially remove the contaminants of concern identified in the aquifer. This stage of evaluation is intended to reduce the number of remedial options that should be given further consideration by eliminating the ones that are not applicable to conditions at the site.

An assessment of the technological suitability involves determining the mass balance distribution of a compound in the groundwater phase (i.e soluble, sinking (DNAPL) and/or floating (LNAPL)). It also involves assessing physical/chemical properties of the compounds found in groundwater. This information provides the basis for selection or elimination of specific remediation technologies under consideration.

4.0 CONVENTIONAL GROUNDWATER TREATMENT TECHNOLOGIES

4.1 Bioremediation

Groundwater clean-up using bioremediation is gaining popularity in North America. One reason for this is the clearer picture of the costs and benefits of microbial

degradation. In many cases bioremediation offers the most cost-effective means of remediating an aquifer.

The vast majority of contaminants that have been treated by bioremediation to date are petroleum derivatives including fuels, petroleum solvents such as acetone and ketones, and polyaromatic hydrocarbons (PAH) found in coal tar and creosotes (Maureen C. Leahy and Richard A. Brown, 1994). The above ground treatment can be very rapid when compared to in-situ treatment, reaching objectives in less than 90 days for removal of petroleum hydrocarbon contamination.

While bioremediation cannot handle metals, and some chlorinated organics still elude it, the technology can destroy many hazardous compounds, including some that resist other forms of treatment. The components of a study to establish the feasibility of bioremediation is given in Table A.

Two techniques are known particularly for using microorganisms to degrade petroleum products:

a) Biostimulation, which involves the stimulation of microorganisms that already exist in groundwater; and
b) Bioaugmentation, which involves culturing of microorganisms in a laboratory and introducing them to the site.

Table A.

COMPONENTS OF A STUDY TO ESTABLISH THE FEASIBILITY OF BIOREMEDIATION (from Lee et al., 1987)

SITE CHARACTERISTICS:

A. Aquifer properties

1. Permeability
2. Specific yield
3. Clay content of soil
4. Heterogeneity of formation
5. Depth
6. Thickness
7. Direction of groundwater flow
8. Recharge and discharge areas
9. Seasonal fluctuation in water table

B. Groundwater quality

1. Inorganic nutrient levels
2. Precipitation of inorganic nutrients
3. Dissolved oxygen content

C. Location of physical structures

D. Groundwater pump controls

E. Potential for contamination of drinking water or agricultural wells

TABLE A Contd.

CONTAMINANT CHARACTERISTICS

A. Type
B. Concentration
C. Areal and vertical extent of contamination
D. Location of released material in aquifer- dissolved, floating, trapped or sinking
E. Heterogeneity of contamination
F. Biodegradability of contaminants
G. Presence and quantity of toxic agents
H. Nature of release - acute, chronic, or periodic
I. Time since release
J. Effect of physical weathering or abiotic reaction on contaminants.

MICROBIAL CHARACTERISTICS

A. Presence of active microbial population
B. Acclimation to contaminants
C. Nutrient requirements for optimal growth
D. Extent of biodegradation that can be achieved
E. Rate of biodegradation

4.1.1 In-Situ Bioremediation

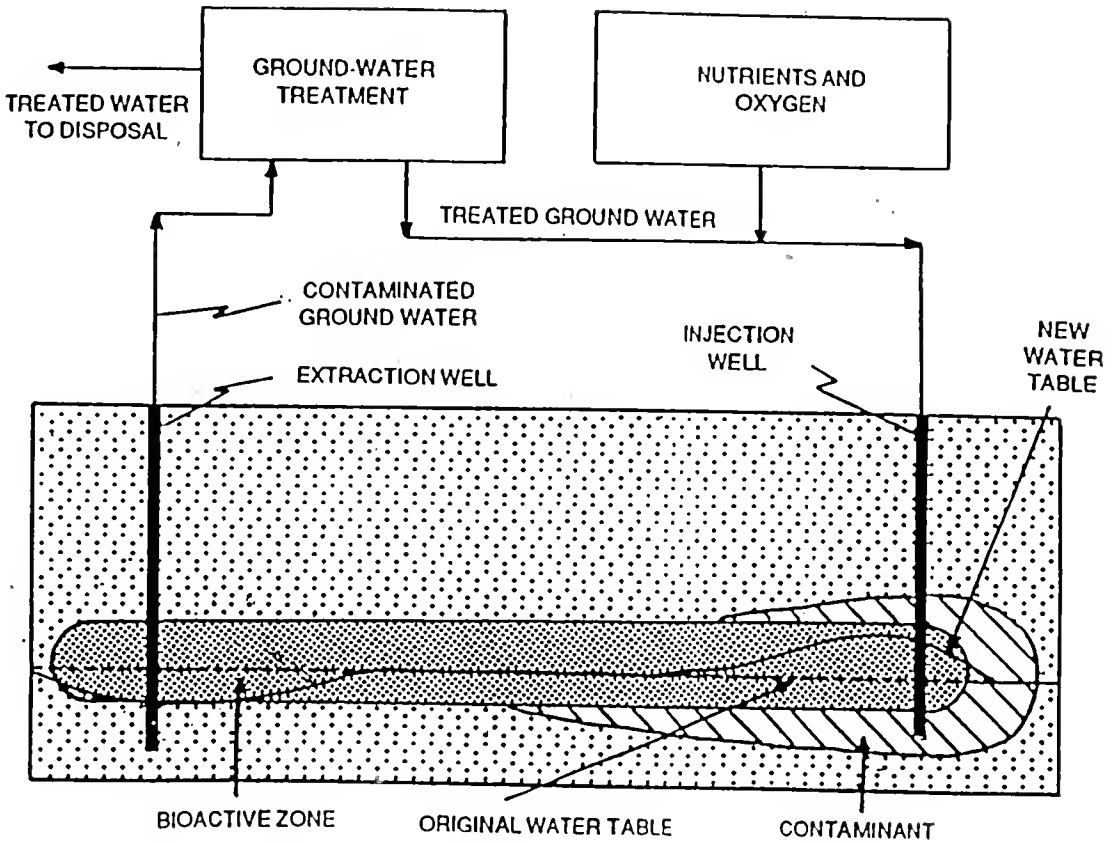
In-Situ bioremediation is the biological treatment of contaminated soils and groundwater without excavation. This method involves the controlled management and manipulation of the microbial process in the subsurface. Generally, treatment consists of optimizing pH, temperature, soil moisture content and the concentration of nutrients to stimulate the growth of microorganisms that will feed on the particular contaminants present (Figure 1).

This technology requires a good understanding of both, the microbiological process relative to biodegradation of the target contaminants, and the soil/groundwater chemical environmental effects on the microbial processes. The rate of biodegradability of organic contaminants varies considerably from hydrocarbons to PCBs.

One of the challenges of in-situ bioremediation is the delivery and mixing of growth substrate and nutrients, such as oxygen and methane needed for the development of the bacterial population. Water is either pumped into the ground or allowed to infiltrate from the surface carrying the nutrients in the subsurface. Benzene, for example, is biodegraded according to the following reaction:

$$C_6H_{12}+9O_2 \dashrightarrow 6CO_2+6H_2O.$$

In general, aerobic biodegradation of petroleum hydrocarbons requires at least 1.359 kg. to 1.585 kg. of oxygen for every 0.453 kg. of hydrocarbons. One kilogram of oxygen can be supplied by 1.698 m^3 of air. A recirculation of water through pumping wells is maintained until the site is finally cleaned.



Source: Adapted from RETEC, Inc.

Figure 1. In-Situ Ground water Bioremediation

In a treatability study of in-situ bioremediation of groundwater contaminated with chlorinated aliphatics, Sempirini et al., 1992, demonstrated that, under ideal conditions, it is possible to achieve 20 percent, 50 percent and 85 percent biodegradation of trichloroethylene, dichloroethylene and vinyl chloride, respectively.

In-situ bioremediation eliminates pumping the contaminated groundwater to the surface, surface treatment and the subsequent reinjection.

Advantages of In-Situ Bioremediation

1. lower cost;
2. large volumes of contaminated groundwater can be treated at one time.

Limitations

1. specific factors such as microbial activity and chemical reaction may limit application;
2. low solubility contaminants do not biodegrade easily;
3. high concentration of metals;
4. homogeneous aquifer.

Costs

In-situ bioremediation is considered to be cost effective. This can be attributed in part, to minimal operational and maintenance requirements, resulting in lower work exposures and reduced health impacts.

Several projects have been completed in the U.S. involving the application of In-situ bioremediation. A cost estimate of about $42 to $60 per liter of residual fuel removed from an aquifer at Kelly Airforce Base has been reported by Abramowicz, et al (1992).

4.1.2. Ex-Situ Bioremediation

If contaminated groundwater is pumped to the surface, it can be treated by a number of technologies including a rotating reactor, fixed film water treatment systems, and activated sludge processes.

Ex-situ treatment allows for better control of the temperature, nutrient concentrations and oxygen availability than is possible with in-situ treatment. In addition, the contaminated groundwater can be moved to another location where treatment can take place, where it does not interfere with redevelopment activities. If redevelopment involves extensive excavation then ex-situ as opposed to in-situ bioremediation methods may need to be employed. The ex-situ treatment approach may also be cost effective since it would be easier to introduce the necessary nutrients to the media than is possible for in-situ treatment. Consequently, it would take a shorter period of time to complete the biodegradation process.

Basic Requirements

For bioremediation method to succeed generally, the following factors must be incorporated into the specific design:

- conductivity > 10^{-4} cm/sec for delivery of nutrients and CO_2;
- homogeneous hydrogeology;
- contaminant characteristics;
- temperature > 10^0C;
- pH 6.5 to 8;
- oxygen (provision of Hydrogen Peroxide, Air, pure Oxygen or Ozone).

Advantages of Ex-Situ Bioremediation

- relative ease of implementation;
- the technology is used on a case by case regional specific recommendation, as a viable treatment technology in Ontario.

Potential Limitations

- clogging of screens and infiltration galleries with fines and microbial growth;
- precipitation reactions (particularly phosphorus) which remove added nutrients and lead to clogging;
- the process may not be applicable to all geological conditions;
- amount of time required to treat groundwater may range from several months to a year;
- rapid decomposition of hydrogen peroxide results in poor oxygen distribution, and slower biodegradation reaction.

4.2 Photochemical Oxidation

Photochemical Oxidation destroys contaminants by chemically converting them to non hazardous or less toxic compounds that are stable and /or less mobile. The oxidizing agents commonly commercially available that are used for the treatment of hazardous contaminants include ozone, hydrogen peroxide, chlorine, hypochlorites, and chlorine dioxide. Chemical oxidation is a developed technology and is commonly used to treat not only contaminated groundwater but also liquid mixtures containing amines, cyanides, and chlorophenols (Freeman, 1989).

The technology is based on ultraviolet light, which in conjunction with oxidants such as ozone and/or hydrogen peroxide influences the photochemical oxidation of organic contaminants. Ultraviolet light will dissociate hydrogen peroxide at a selected wavelength producing hydroxyl radicals which oxidizes the organic contaminants to carbon dioxide and water, thus carrying the reaction to completion (Gurol and Vatistas, 1987). In the case of ozone, however, the ultraviolet radiation dissociates ozone into oxygen molecules.

The ultra-violet/oxidant system keeps the organic species active and makes them more vulnerable to attack by the hydroxyl radicals provided by the oxidant. During the treatment process, a combination of ozone and/or hydrogen peroxide with ultraviolet light create a powerful oxidizing agent that enhances destruction of organics (Figure 2).

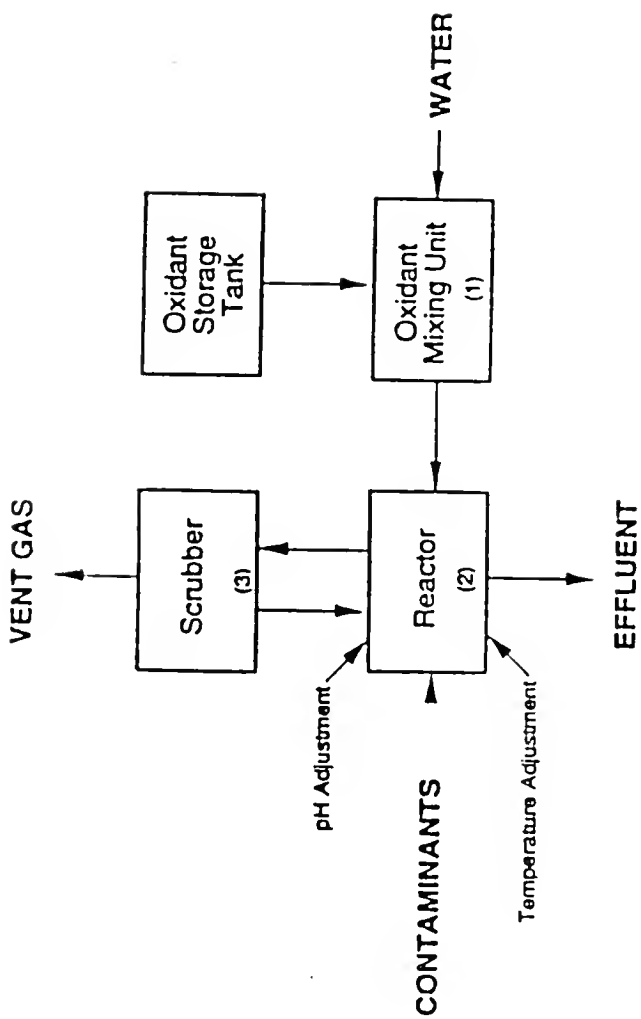


Figure 2. Process Flow Diagram For Chemical Oxidation System
(H.M. Freeman, 1989)

Progress of Reactions

The chemistry of the photochemical oxidation of simple hydrocarbons may be illustrated by the following basic reactions (Paul and Canter, 1991):

Hydrogen Peroxide

H_2O_2 (Hydrogen Peroxide) $\xrightarrow[254\ nm]{\text{UV Light}}$ $2(^{*}OH)$ (Hydroxyl - radicals)

Ozone

O_3 (Ozone) $\xrightarrow[254\ nm]{\text{UV Light}}$ $O_2 + O(^{1}D)$ (D-state Oxygen atom)

$O(^{1}D) + H_2O \longrightarrow 2(^{*}OH)$ (Hydroxyl Radicals)

Oxidation of Organics

Organic Molecule + $x(^{*}OH)$ $\xrightarrow[254nm]{\text{UV Light}}$ $yCO_2 + zH_2O$ + Heat + Acids

where **x,y,z** are the stoichiometric numbers of hydroxyl radicals, carbon dioxide, and water participating in the reaction.

UV = Ultraviolet light

The oxidation reactions are perceived to take place in three steps (Prengle, 1983):

(1) partial oxidation of the original substrate to form intermediates;

(2) oxidation of primary intermediates to form secondary intermediates, and;

(3) further oxidation to form innocuous end products or stable organic acid species.

For the purpose of clarity, the ultraviolet light functions in three basic ways (Fletcher, Leitis and Nguen, 1989):

(1) transforms ozone and/or hydrogen peroxide to highly reactive radicals;
(2) excites organic molecules to a higher energy level; and
(3) initially attacks the target organics thus resulting in their partial degradation by UV light.

Some of the Important Process Variables

(1) Variables related to the contaminated groundwater:
    a) type and concentration of organic contaminants;
    b) light transmittance of the water;
    c) type and concentration of dissolved solids.

(2) Variables related to treatment process design and operation:
    a) UV dosage;
    b) oxidant dosage;
    c) temperature - higher temperatures improve photochemical oxidation reaction of most organic compounds;
    d) pH > 8;
    e) homogeneous hydrogeology.

Advantages of Photochemical Oxidation

1) the technology is believed to truly 'remediate' contaminants instead of 'relocating' them when compared to a number of conventional technologies that tend to transfer the problem from the water phase to the air or land;
2) it can be far more economical than conventional technologies;

3) it is simple and needs minimum operator - attendance and maintenance.

Limitations

1) the technology is basically designed for destroying hydrocarbons in dilute concentrations in groundwater or waste water;
2) when used for concentrated aqueous wastes the process requires long oxidation times, hence higher costs;
3) process does not address the free product phase (waste in its natural state) in the subsurface.

Process Costs

Cost requirements for the Photochemical Oxidation method are largely influenced by the size and design of the equipment, system configuration and capacity. Also equally important are the process parameters such as the concentration and nature of the organics and the required treatment efficiencies. Capital costs will, therefore, vary significantly with variation in the above parameters. Estimated capital costs range from $0.08 to $0.53/liter of capacity (Major and Fitchiko, 1990)

4.3 Air Stripping

Air Stripping is one of the demonstrated effective treatment technologies used to remove volatile organic compounds such as Benzene, Toluene, Ethylbenzene and Xylenes (BTEXs) from hydrocarbon contaminated groundwater.

The basic concept behind air stripping is to bring the contaminated water into direct contact with air so that volatile compounds undergo a change (from liquid to vapour). At that stage the air will carry off the contamination leaving the water free from these compounds (Figure 3). This technology alone, however, can not be used to effectively clean-up groundwater laden with high molecular weight hydrocarbons e.g. Phenolics and PAHs found in fuel oil.

Air Stripping at specific design and operating conditions will yield a fixed, compound-specific percentage removal. The technology has been used primarily for the treatment of VOCs in dilute aqueous waste streams.

Advantages

a) can be used to treat large volumes of water with elevated concentrations of organic compounds at relatively high groundwater flow rates;
b) reliable performance to meet objectives/standards with minimal operational and maintenance costs.

Disadvantages

a) most effective where water has low level of BTEXs (< 10,000 ug/L). Alternatively it requires chemical or physical pre-treatment;
b) high capital costs;
c) limitation with regard to complete removal of hydrocarbons;
d) large tracts of land are required so that neighbouring properties are not affected by wind-driven mists or, in winter, ice crystals;
e) potential for dealing with aesthetics and noise problems in residential neighbourhoods.

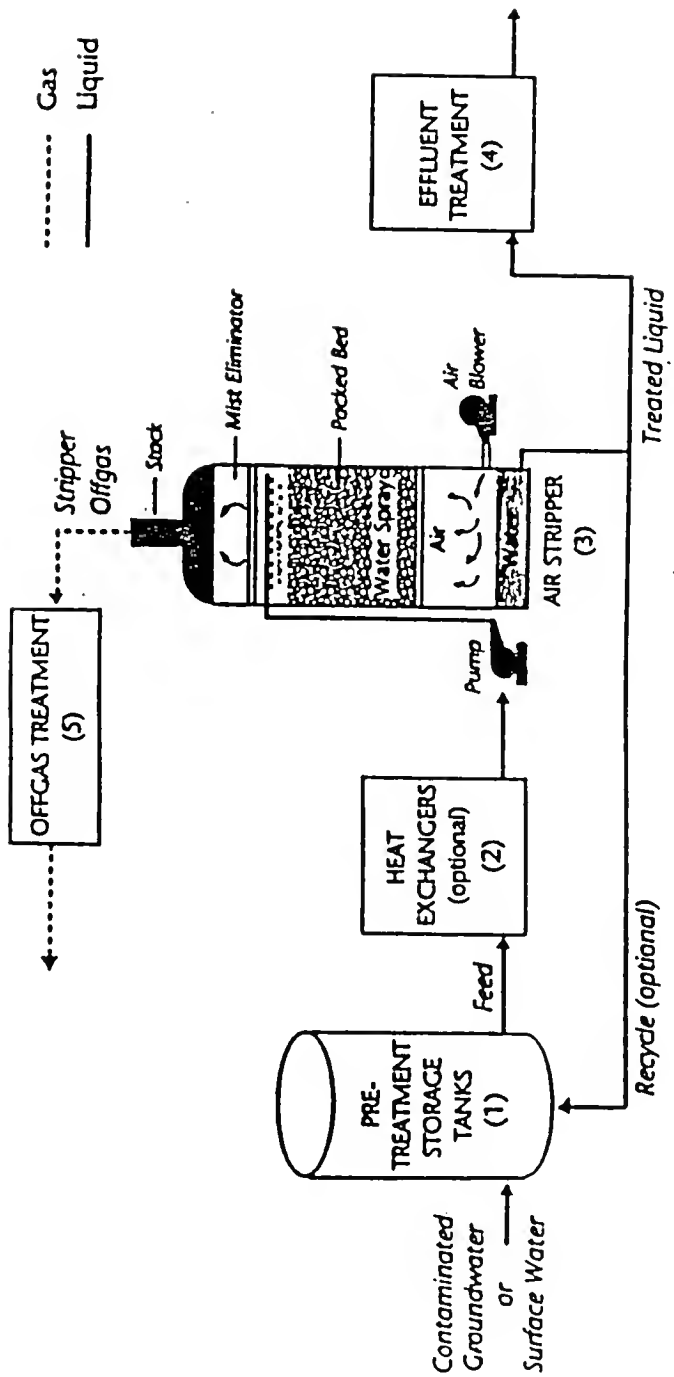


Figure 3. Schematic diagram of Air Stripping System (H.M. Freeman 1989)

Costs

The factors determining the cost of an air stripper can be categorized as those dealing with design, emission controls, and operation and maintenance.

According to Freeman (1989), the cost of air stripping in the United States may range from US$0.04 to US$0.17 per 1,000 gallons or 3,785 litres treated. At a Superfund site in Des Moines in the U.S., the unit cost for groundwater treatment is estimated to be about US$0.45 per 1000 gallons based on a 1,250 gpm treatment rate.

4.4 Carbon Adsorption

Carbon adsorption involves the removal of dissolved organic compounds from the groundwater by adsorbing the compounds on activated carbon. This is accomplished through pumping groundwater from the ground and letting it pass through an adsorption chamber.

This technology is well developed, commercially available and is most effective for compounds with low solubility such as PAHs and least effective for compounds with relatively high solubility e.g. BTEXs, chlorinated solvents, phenols and alcohols. Compounds with high solubility have a tendency to desorb from the carbon. Carbon adsorption is not suitable for treating groundwater contaminated with metals.

The costs of carbon adsorption treatment tend to escalate with higher concentrations of organics and treatment may require large volumes of carbon. In an attempt to reduce operating

costs carbon adsorption is often used as a supplementary treatment method in conjunction with an air stripping process. This is particularly useful when large volumes of high level organic contamination are found. Carbon adsorption treatment alone is usually used only in areas of very low groundwater contamination.

Advantages

1. effective for removing most dissolved organic compounds especially those with low solubilities;
2. contamination from a large volume of groundwater can be concentrated into a much smaller volume of carbon, reducing the cost of off-site disposal.

Limitations

1. this technology is most effective when used in conjunction with air stripping in areas of extensive contamination;
2. cost of treatment tends to escalate with high concentrations of organics and large volumes of water requiring treatment;
3. carbon units reach a saturation level after which the units require regeneration;
4. pretreatment may be necessary.

Costs

Costs associated with Carbon Adsorption treatment are dependent on waste stream flow rates, type of contaminants, and site and timing requirements.

Costs are lower with lower concentration levels of a contaminant of a given type. Costs are also lower at higher flow rates. Studies conducted in the U.S.A by O'Brien, R.P. (1983); and Freeman, H.M. (1989) show that at flow rates of 100 million gallons per day (mgd), the costs for Carbon Adsorption ranged from US$0.10 to US$1.50 per 1,000 gallons treated. This value is not likely to vary much with time. But the type of concentration would affect the total cost.

4.5 Physical Barriers

These are low permeability cut-off walls or diversions installed below ground to contain, capture or redirect groundwater flow in the vicinity of a site to depths of up to 70m. The walls are also used to control migration of DNAPLs, LNAPLs and /or other contaminants in the subsurface. In so doing, they enhance the effectiveness of remediation efforts such as Pump-and-Treat, and may decrease the financial burden of site remediation by reducing the physical spread below ground. Cut-off walls (barriers) can be used in conjunction with other recovery means.

Types of Barriers:

1) Bentonite-soil walls;
2) Concrete panel walls;
3) Plastic membrane walls;
4) Sealable-joint steel sheet piling walls;
5) Reactive Barriers;
6) Microbial Bio-Barriers.

Applications

A detailed discussion of the various types of barriers is beyond the scope of this report. However, some observations are worth mentioning.

A review of the configuration and design options available is vital to determine which one best meets the goals of the remediation action.

- Cut-off walls may be keyed into an aquitard[1] (Keyed wall) or not keyed (Hanging wall);
- Cut-off walls may be placed relative to the direction of groundwater flow, that is, up gradient, down gradient or completely surrounding the remediation site.

Reactive Barriers - Permeable reactive barriers represent the latest innovation in subsurface barriers. These barriers are based upon a principle that involves installation of reactive walls within the paths of the contaminated plume. Reactive barriers operate similar to cut-off walls except that they are permeable. This technology is still being tested in the field. Reactive walls have the potential to be entirely passive, reducing long term operating costs and once installed are non-invasive in that there are few, if any, above ground facilities to disturb site development. Interested readers are referred to Gillham, R.W. and Buris D. (1992), and Starr, R.C and Cherry J.A., (1992)

[1] A bed or beds of lower permeability adjacent to an aquifer

Applications

The methods of installing reactive barriers include excavation and replacement, in-situ mixing of the reactive materials with the native geologic material and fence-gate systems in which the groundwater is funnelled through narrow zones of the reactive materials. In practice, groundwater flows through a reactive barrier in which contaminants are adsorbed or degraded.

Potential Limitations

- Bentonite slurry walls can be limited by the site topography;
- sufficient work area is required besides the trench to mix and place the back fill, and also to allow for easy movement of heavy equipments;
- Chemical compatibility of wall components must be established;
- site characterization and remediation options (for sites containing DNAPLs) are limited;
- field data from site characterization and remediation efforts are limited;
- it is difficult to test the cut-off wall during or after construction to determine if it meets the design specifications;
- standard testing programs may not indicate the location of imperfections or failure points.

4.6 Air Sparging (In-Situ Air Stripping)

Air Sparging is a method by which oxygen is introduced into

the ground or recirculated water through the use of an air compressor. This action results in volatilization of some petroleum hydrocarbons (HC) contaminants. Under air sparging method air bubbles are made to traverse horizontally and vertically through the natural soil column, creating a transient air-filled porosity within the saturated zone. Air sparging effectively creates an air stripper in the subsurface (Figure 4).

The air is injected into the subsurface and allowed to flow upwards and in contact with waste source, soil, and water. Air bubbles coming into contact with contaminants cause volatilization of volatile organic compounds (VOCs). The volatilized organics are carried by the air bubbles through the unsaturated zone where it is captured using a vapour extraction system.

Air sparging creates turbulence and increased mixing in the saturated zones, which increases the contact between air, water and soil. This results in the removal of the VOCs dissolved in the groundwater and adsorbed to the soil which is recovered.

This method also provides a limited oxygen source for enhancement of biodegradation in groundwater. The source is limited to the solubility of the oxygen (approx. 8 - 10 mg/L) at the temperature of the groundwater. Although the oxygen source is limited, laboratory and field evidence suggest that microbial populations can initiate oxidation of hydrocarbons and then further degrade those hydrocarbons, given minute amounts of oxygen (R.E. Hinchee et al, 1987). Depending on the situation, the vapour phase volatile organic compounds (VOCs) in the gas generated by sparging may need further treatment prior to release to the atmosphere.

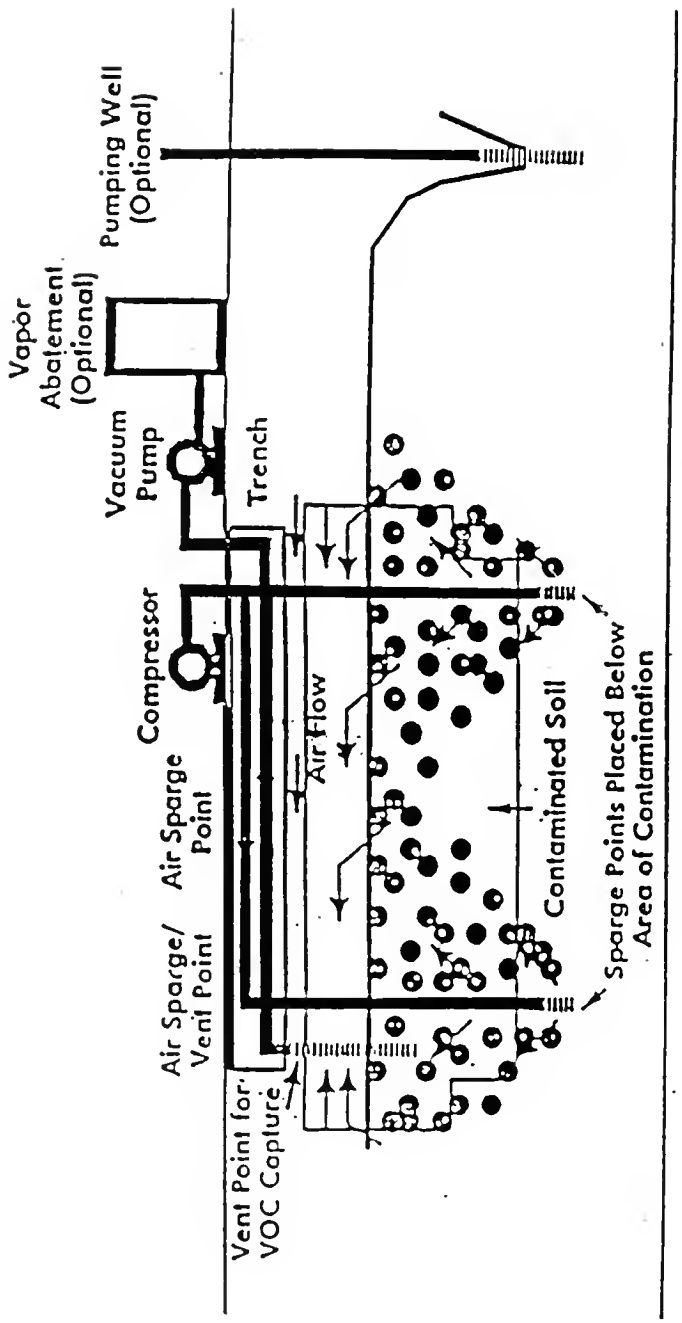


Figure 4 Elements of an Air Sparging System
(From Brown R. and F. Jasiulewicz, 1992)

Advantages

1. when used in conjunction with vapour extraction, air sparging has been proven to be an effective means of groundwater clean-up of VOCs;
2. allows hazardous wastes to be treated on site;
3. the technology is cost effective and commercially available.

Disadvantages

1. possibility of spreading dissolved contamination due to local hydraulic disturbance of groundwater flow pattern, and possible subsurface migration to buildings due to generation of vapour phase contaminants;

2. changing in site groundwater flow pattern due to sparging, specifically water table mounding could increase down gradient.

Costs

The costs associated with the removal of adsorbed contaminants from the soil and groundwater using Air Sparging technology have decreased considerably over the past five years in the U.S.A. The typical length of treatment to achieve site closure was also reduced from five to two years at costs dropping from US$ 1 million to about $500,000 (Brown and Jasiulewicz, 1992). Extensive testing and treatment sites in the U.S. indicate that Air Sparging continues to compete as a viable, cost effective treatment technology for groundwater contaminated with VOCs.

4.7 Vacuum Extraction

This is an in-situ process that removes volatile and semi-volatile contaminants directly from the soils and groundwater without excavation of the soil. Waste constituents are removed in situ by the technology but are not actually destroyed.

Groundwater is removed simultaneously from vacuum extraction wells to further enhance the recovery of the contaminants and reduce the period of cleanup. The process involves the use of a vacuum blower. The induced air extraction eventually comes into equilibrium with the in-situ replacement air (Figure 5).

Prior to full-scale remediation, an assessment of the subsurface conditions is required. This assessment may include a delineation of subsurface contaminants existing in distinct plumes. These plumes may include:

1. liquid phase contaminants on the water table;
2. dissolved contaminants within the aquifer;
3. residual contaminants within the soil matrix;
4. vapour plume emanating from the other plumes.

Initial focus of the subsurface investigation is often the delineation of the groundwater plume or dissolved and non-aqueous liquid phase plume. This can be accomplished using groundwater monitoring wells. A vacuum extraction system is designed to remove volatile contaminants directly from all the four above types of plumes, eliminating further contamination of the groundwater

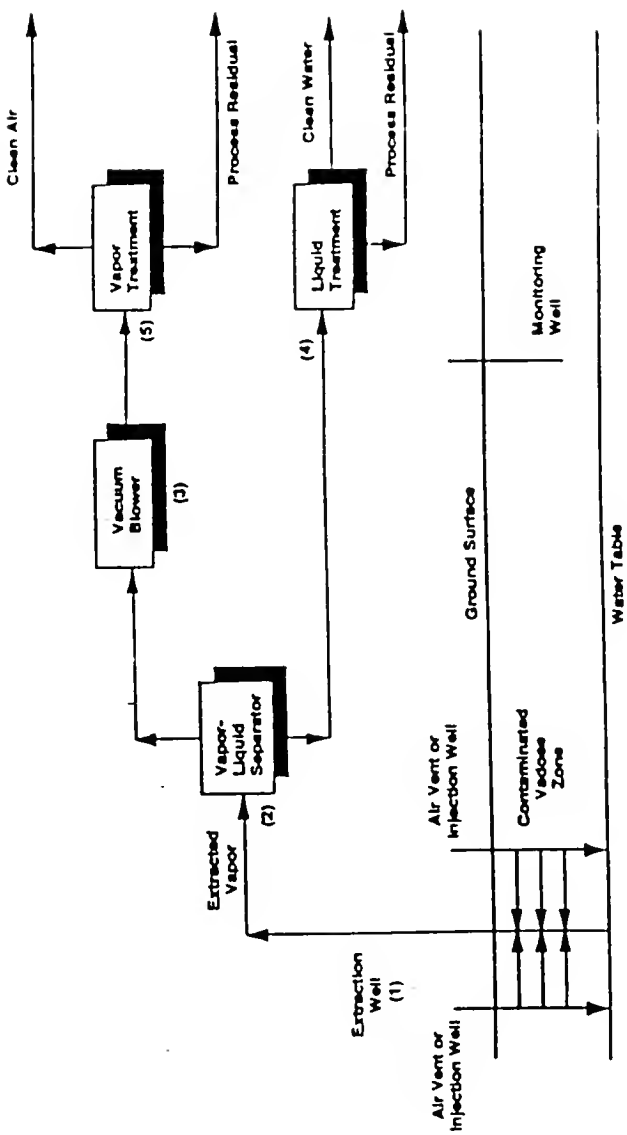


Figure 5. Process Schematic of the In-Situ Vapour Extraction System (H.M. Freeman, 1989)

Vacuum extraction process when conducted in combination with pump-and-treat can be a very effective groundwater remediation technique. The technology has been demonstrated to be effective in virtually all hydrogeologic settings: clay, silts, gravel and in fractured rocks.

Advantages

1. removes volatile and semi-volatile organics;
2. provides permanent remedial action for VOCs;
4. cleanup of groundwater and soil in situ is rapid and at relatively lower costs;
5. does not require additional reagents;
6. can provide continuous monitoring of underground tanks and cleanup of any leakage detected;
7. simultaneous extraction of groundwater and vapour is possible and enhances rate of groundwater cleanup.

Limitations

1. a site with wastes of different volatilities would require additional remedial technologies;
2. technology is most effective for highly volatile compounds.

Costs

Costs associated with vacuum extraction are highly variable due to site variations as well as contaminant characteristics that impact on the treatment process. For a stationary vacuum extraction system, the most important factor influencing costs is the number of wells required per unit area which related to

the depth of contamination and soil permeability. In the U.S.A., cost estimates for this technology, according to Udell et al. (1989) range from about US$40- US$230/ cu.meter.

5.0 INNOVATIVE GROUNDWATER TREATMENT TECHNOLOGIES (at various stages of development)

Introduction

Research workers everywhere are tireless in their struggle to improve subsurface groundwater cleanup technologies. This section presents a snapshot of some of the many new ideas on groundwater cleanup technologies that have appeared in professional and trade journals. While some are still at laboratory scale, others have undergone preliminary field tests. In general, however, the following technologies have not been adopted as a viable technology at this stage.

For interested readers, a list of technologies being evaluated under the Superfund Innovative Technology Evaluation (SITE) program as of October 1994 is attached as Appendix III.

5.1 Dynamic Underground Stripping

This is a rapid clean up technology developed at the Livermore National Laboratory, in California. The technology is effective for organic wastes in localized underground plumes. A combination of steam injection and electric heating is used to heat the waste so it migrates to a central extraction well. There it is pumped to the surface and cleaned using conventional or other treatment methods. This technique is

thought to reduce cleanup time for concentrated spills from years to months.

5.2 Bio-Tower Biological Treatment Units

This method is intended for aerobic or anaerobic biological treatment of groundwater contaminated with organic substances such as acetone, methyl ethyl ketone, and benzene. The technology was developed and is being perfected by Lancy Environmental Systems (Warrendale Pa.). It is best suited for treatment of influent water containing less than 3,000 mg/l BOD for aerobic systems, and up to 50,000 mg/L BOD for anaerobic systems.

The Bio-Tower Systems typically consist of one or two vertical reaction tanks filled with randomly packed polypropylene rings.

Application include treatment of landfill leachate and contaminated water generated by petroleum refining, food processing and coal gasification.

5.3 Enzymes Detoxifying Pesticide-contaminated Soil and Water.

A variety of methods are currently used for detoxification of pesticides. These include chemical, physical and biological methods. Pesticides rank as medium on the biodegradability ranking scale of organic contaminants.

Conventional subsurface clean-up methods for pesticides removal are generally cumbersome and cost prohibitive. The biotechnology involving the use of microorganisms or their

cell-free enzyme preparations to control pesticide pollution appears to have most promising application at the moment.

There are advantages that favour the application of enzyme technology to the detoxification of pesticides e.g. Enzymes are unaffected by inhibitors of microbial metabolism and can often be used under conditions that would be detrimental to active microbial cells. Because many enzymes that are usually active within the cell also function outside of the cell, cell-free enzyme systems may be applied to subsurface detoxification of pesticides.

In spite of the promising potential applications, only a few enzymes have been tested as tools in the detoxification of pesticides in waters and soils. Numerous investigations have documented the degradation of pesticides by soil and water microorganisms; but few studies have examined the enzymes responsible for pesticide degradation. In addition, effective methods for bringing the enzymes in contact with the soil and water below the water table need to be evaluated.

5.4 Application of Polymers

This technology was originally developed to clean-up surface oil, where polymers render it cohesive and amenable to skimming. The technology has since been found to be very effective in accumulating dissolved organics.

An elasto-polymer that can be used to remove dissolved and suspended organics from water was recently developed in Virginia by General Technologies Inc.

This technology involves the pouring of the elastro-polymer on the surface where it is mixed into the water by moderate air

sparging. The resultant mixture rises to the surface where it can then be removed. The amount of polymer used, the time required for air sparging and the rise time all depend on the waste water being treated.

Bench scale experiments were conducted by the developers with tank bottom water from a bulk petroleum fuel tanks. Raw waste samples taken from the bottom contained 139,700 ppb of BTEX. Results of the treatment indicated a steady decrease in contamination levels for most of the volatile organic compounds detected earlier. The technology is still undergoing rigorous field tests.

5.5 Electrokinetics

Electrokinetics are used to induce an electric field in the subsurface. This method has been developed to assist in soil dewatering in low permeability materials. The method has been identified by U.S. EPA and other agencies for improving the effectiveness of the pump-and-treat system by inducing and improving groundwater flow rate. Groundwater in the pore spaces is drawn towards the cathode due to a phenomenon called "viscosity drag". Consequently, investigations in the application of electrokinetic methods are focusing on whether positively charged organic and inorganic contaminants could behave in the same way.

Experimental results have shown elevated concentrations of contamination in water adjacent to energized cathodes. Laboratory and field test results from commercial applications in Europe indicate effective removal levels for a wide range of heavy metals from groundwater.

5.6 Surfactant Mobilization

Surfactants may be added to groundwater in pump-and-treat processes to increase the solubility of one or more target contaminants. Because the contaminant concentration in the groundwater increases, the overall removal process is accelerated. Surfactants also reduce the interfacial tension of non-aqueous-phase liquids (NAPLs), directly mobilizing them. One of the field tests on surfactant mobilization is being conducted at the Atlanta Testing and Engineering, in Florida. This study is headed by Valerie Francisco.

Surfactant mobilization may improve extraction efficiency. The method, however, has one notable disadvantage. While the extraction efficiency is improved, the process may cause the NAPLs to migrate to previously uncontaminated regions of the aquifer. This enhanced recovery approach is currently being researched by a number of laboratories and firms.

5.7 Funnel- and- Gate Concept

At numerous contaminated sites, plumes of groundwater contamination emanate from subsurface source zones. Pump-and-treat could provide an effective means of hydraulically containing the dissolved contaminants emanating from these sources, however, at many sites pump-and-treat will have to continue for many decades because the source zones dissipate very slowly. A new approach for zone source containment has been developed at the University of Waterloo and it is called the funnel-and-gate system.

The funnel-and-gate system has undergone intensive tests and

verifications. The technology is designed for in-situ treatment of contaminated plumes and consists of low hydraulic conductivity cut-off walls with gaps that contain in-situ reactors designed to remove contaminants by abiotic or biological process.

The funnel-and-gate system containing in situ reactors can be installed at the front of plumes where they can intercept the flow of all contaminated groundwater and thereby prevent further plume growth. Studies conducted by J. Cherry and R. Starr (1994); and D.A. Smith, J. Cherry and R. Jowett (1994) suggest that in situ reactors such as reactive porous media can be effectively used to remove contaminants by biological processes.

Cut-off walls (also known as the funnels) are installed in such a way that they modify flow patterns so that groundwater flows primarily through high conductivity gaps (Figures 6 and 7). The approach is largely passive in that after installation, the in-situ reactors are intended to function with little or no maintenance for long periods.
The gates can be designed so that contaminant degradation or treatment occurs within the gate or within a zone of bacterial enhancement immediately downgradient of the gate. The conceptual designs for application are still under development.

5.8 Microbial "Biofilter"

Researchers from the Lawrence Livermore National Laboratory in California demonstrated an underground biofilter that uses living organisms to clean-up solvent contaminated groundwater. This is a new revolutionary concept and it differs markedly from the in-situ bioremediation technology.

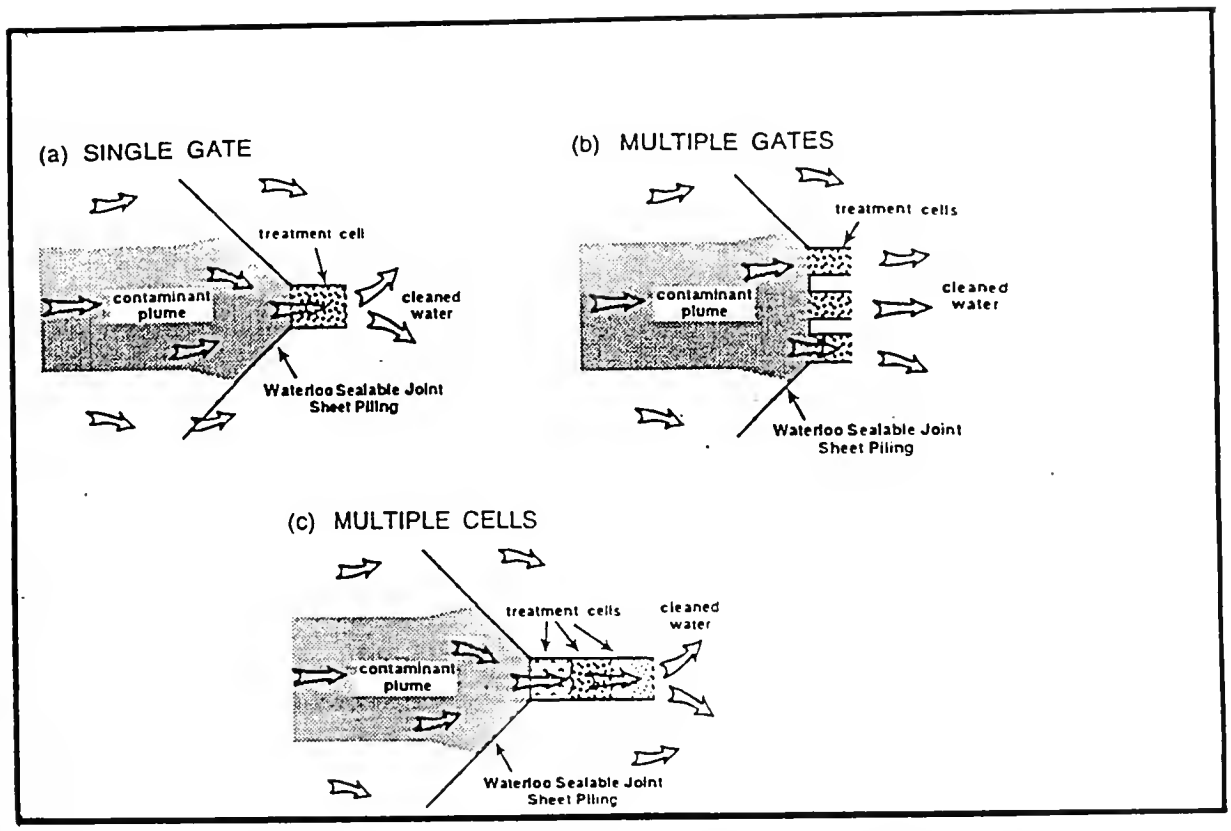


Figure 6: Three conceptual configurations of funnel-and-gate systems in plan view. Figure 6a shows a simple system with one single-chamber or single-cell gate. Figure 6b shows a system with three single-chamber gates in parallel. Figure 6c shows a system incorporating several chambers or gates in the treatment gate to accommodate a sequence of treatment steps. (Smith, Cherry and Jowett, 1994)

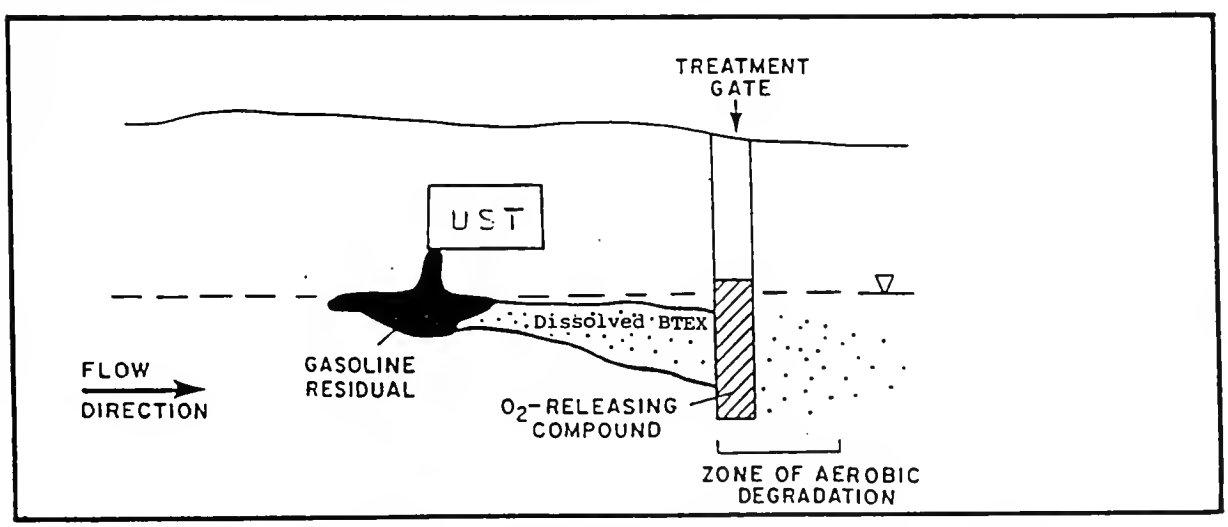


Figure 7.: Enhanced biodegradation of BTEX in a funnel-and-gate system. Oxygen is released from the treatment mediain the gate, and aerobic biodegradation of BTEX occurs within and immediately downgradient of the gate. (Smith, Cherry and Jowett 1994)

Significant improvements have been made to increase underground bacterial population but often the infusion of nutrients causes the contaminants to get pushed away from the microbes thereby slowing down the clean-up process. While in-situ bioremediation is based primarily on the injection of nutrients into the ground to stimulate the growth of bacteria already present, in the new Biofilter method no nutrients are infused. The starving bacteria are the ones that are relied upon to destroy all prevailing contaminants before the microbes become inactive.

At one of the test locations in California, where groundwater was contaminated with the common solvent trichloroethylene (TCE), the lab scientists used an underground filter of harmless soil bacteria to dramatically reduce contaminant levels from approx. 400 parts per billion (ppb) to less than 10 ppb. When a determined amount of a target bacteria e.g. **Methylosinus trichosporium 0B3b** was injected into the plume, the microbes adhered to surrounding soil particles, forming a spherical microbial mass around the end of the injection well.

The scientists then began drawing on the well. This resulted in the pulling of contaminated groundwater from the surrounding area through the mass of microbes, into the well bore and up to the surface. As the contaminated water passed through the mass of bacteria, enzymes within the organisms began breaking down the TCE in harmless aqueous carbon dioxide and water. The lab scientists confirmed that they were able to achieve 98% degradation of the contaminants in groundwater. This technology is still undergoing tests and is not commercially available.

5.9 The Forager Sponge Technology

This new technology was developed by Dynaphore, Inc. in New Jersey and evaluated at the NL Industries site, in Pedricktown, New Jersey. The Forager Sponge is an open-celled cellulose sponge incorporating an amine-containing chelating polymer that has selective affinity for dissolved heavy metals in both cationic and ionic states. This technology has the ability to remove heavy metals from contaminated groundwater. According to the developer, it can also be utilized to remove and concentrate heavy metals from a wide variety of other contaminated aqueous media such as surface water, landfill leachate and industrial effluents.

The Sponge is highly porous, hence it promotes high rates of absorption of ions. The polymer in the Sponge provides ligand[2] sites that surround the metals to form complexes, especially with ions of transitional group heavy metals. The Sponge, which can be used in columns, fishnet-type enclosures or rotating drums, has the ability to preferentially bind toxic heavy metals. This is particularly beneficial for the treatment of contaminated natural waters and has advantages over conventional ion exchange or precipitation technologies where valuable ion exchange chemicals are wasted because they also remove cations such as calcium, magnesium, aluminum, sodium and potassium.

For the tests and demonstrations conducted at NL Industries Inc. in New Jersey, the technology effectively achieved a 97% removal of copper and lead from average influent concentrations of 917 micrograms per liter (ug/L) and 578

[2] Anions in close association with a metal cation

ug/L, respectively. There was reported 90% removal of cadmium from influent concentrations of 537 ug/L. Although the developer's treatment claims for copper, cadmium and lead were achieved, the treatment claim for chromium fell short, with only 32% removal of chromium out of initial concentration of 426 ug/L. This technology which is under the EPA's SITE (Superfund Innovative Technology Evaluation) program is still undergoing tests and scrutiny.

5.10 Dehalogenation with Metal Catalysts

This is a new physical/chemical method of treating contaminated groundwater. Most physical/chemical techniques lend themselves to application in above-ground reactors. However, few are appropriate for in-situ implementation largely because of the difficulties in effectively contacting the contaminants with the catalyst.

This technology uses an iron catalyst to remove dissolved halogenated organic compounds from groundwater and was developed at the University of Waterloo, in Ontario. The process involves constructing a permeable treatment wall across the path of a contaminated groundwater plume. When the contaminated groundwater comes into contact with iron materials in the wall, the halogenated organics are degraded to non-toxic by-products.

This technology is offered as a cost-effective alternative to groundwater pump-and-treat systems. In addition, contaminants are degraded below ground thereby offering an advantage over methods that simply transfer contaminants from one medium to another (e.g Spent Activated Carbon).

A wide range of metals were investigated for use as catalysts for dehalogenating organic compounds in groundwater. The test results obtained at the University of Waterloo indicate that galvanized metal and mild steel caused the highest and most rapid dehalogenation rates. From the data, the researchers hypothesized that the oxidation of the metals caused a lowering of the redox potential[3] (Eh). Based on the results and also considering factors such as cost and availability, iron was selected as the most appropriate catalyst.

The pilot tests conducted indicated that this technology can effectively degrade halogenated organic chemicals. However, further rigorous tests are needed to establish:

1. its long-term integrity and effectiveness in a variety of hydrogeochemical environments;
2. its potential for formation of toxic break-down products (e.g dichloroethene).

5.11 Algasorb - for Removal and Recovery of Metal Ions

In recent years increased attention has been focused on pollution of water supply by heavy metal ions. These metals are toxic in rather low concentrations but can lead to acute and chronic illness in humans and other animals.

Past disposal practices have resulted in serious contamination of the environment. The major sources of heavy metals are leachates from legal and illegal landfills and drainage from old mines.

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[3] Measured electrode potential for an electrochemical cell

Chemical treatment using lime or caustic precipitation has been the most common method of removing dissolved metals from leachate, mine drainage, and contaminated aquifers. Other treatment methods include reverse osmosis, electrodialysis and carbon adsorption. A serious limitation of many of the current treatment technologies is the difficulty of treating waters for removal of heavy metals to allowable drinking water levels.

"Algasorb" is a new sorption process for removing toxic metal ions from groundwater. This technology was developed by Bio-Recovery Systems Inc., in New Mexico.

Algasorb is based upon the natural, very strong affinity of biological materials such as the cell walls of plants and microorganisms for heavy metal ions. Biological materials, primarily algae, have been mobilized in a polymer to produce a biological ion exchange resin called "Algasorb".

Numerous tests of Algasorb resin conducted show promise for mercury recovery from contaminated groundwater. Test results have shown many groundwater samples with mercury concentrations of about 1500 ppb being reduced to effluent concentration of less than 10 ppb.

Advantages of "Algasorb"

a) the process has high affinity for metal ions;

b) it can be used to remove aluminum, cadmium, chromium, cobalt, copper, gold, iron, lead, manganese, mercury and molybdenum;

c) the efficiency of heavy metal ion removal is not diminished by the presence of organic compounds in the groundwater.

5.12 Adsorptive Filtration

Treatment of groundwater contaminated with toxic metals is complicated by the wide range of concentrations which may be present and the complexity of the matrix.

Although highly concentrated metal ions may be treatable by conventional precipitation processes, these processes may not meet the stringent effluent discharge requirements.

Adsorptive Filtration is a new process being tested at the University of Washington in the Department of Civil Engineering. This technology combines an efficient sand filter with an adsorptive process capable of lowering metal concentrations well below levels achievable by precipitation.

The new process uses conventional sand filter in which the sand is first coated with iron oxide. Iron oxide surface has a strong pH reversible affinity for the metals.

This process, now being tested, is applicable to anionic metals such as chromate, selenite, and arsenate, which are difficult to precipitate efficiently.

5.13 Application of Transportable, Multiphase Bioslurping Treatment Technology

This is an innovative soil and groundwater treatment technology designed by Jacques Whitford Environment Limited in

Markham, Ontario. The technology is an in-situ bioslurping treatment system that can flush contaminants and enhance their degradation.

The system is fully transportable and can be housed in a modified shipping container and dubbed the Transportable Remediation Unit or TRU.

The TRU represents an innovative, cost effective, hybrid approach to petroleum hydrocarbon treatment by employing a variety of aggressive treatment technologies (together traditionally termed Bioslurping or Air Induction) including: a high vacuum multiphase (for free-phase liquid hydrocarbons and groundwater) and soil vapour extraction system. Groundwater is treated using plate coalescing oil/water separation, low profile diffused air stripping and liquid phase carbon polishing, where required.

The technology has the following unique features:

1. all processes are automatically controlled using a Programmable Logic Controller (PCL);
2. system monitoring, diagnostics and logic adjustments may also be conducted using remote telemetry PCL access by high speed modem;

3. free-phase liquid hydrocarbons, groundwater and petroleum vapours are recovered by the TRU using the same piping network and specially designed vertical bioslurping wells.

<u>Costs:</u>

Treatment cost was estimated to be approximately Can$100 to

$120/tonne of contaminated soil but the net cost is expected to go down to $30 to $50/ metric tonne in the long term. The cost for treating groundwater is also down by about half by comparison to other traditional treatment methods (such as Carbon Adsorption).

6.0 CONTAMINATION BY NON-AQUEOUS PHASE LIQUIDS (NAPLs)

6.1 Characteristics and Remediation Strategies

Groundwater contamination by organic chemicals such as chlorinated solvents, petroleum fuels, coal tar and creosote, is a serious concern at many industrial facilities and waste disposal sites. These chemicals, in pure form, are immiscible with water. Liquids that do not readily dissolve in water and can exist as a separate fluid phase are known as non-aqueous phase liquids (NAPLs).

NAPLs in the form of immobile residual contamination, or pool of mobile or potentially mobile NAPL, can represent continuing sources of groundwater contamination unless **NAPL zones** are removed from the subsurface, isolated from the groundwater system, or treated in-situ.

Studies by Schwille (1967, 1981) demonstrated that NAPLs can be classified into two groups depending on their density relative to water. Those that are lighter than water (LNAPLs) and those with a density greater than water - the Dense Non-aqueous Phase Liquids (DNAPLs).

Liquids heavier than water tend to move downward through the capillary fringe and the water table, while liquids lighter than water tend to spread laterally when they encounter the

capillary fringe and the water table (Schwille, 1981, 1984; Reinhard et al, 1984). NAPLs, particularly DNAPLs, have become a serious groundwater contamination problem in North America and Europe. Concern about these chemicals exists largely because of their persistence in the subsurface and their ability to contaminate large volumes of water. For example, 7L or 10 kg of trichloroethylene (TCE) can contaminate 10^8 L of groundwater to a concentration of 0.1 mg/L or 20 times the drinking water standard of 0.005 mg/L (Feenstra and Cherry, 1987).

Presently, there are no approved, effective methods that can be used to clean-up aquifers contaminated with DNAPLs. However, relentless efforts are being made to develop effective technologies. Apparently, this will require containment of groundwater and DNAPL within the DNAPL zone. DNAPL chemicals are known to be distributed in several phases i.e. dissolved in groundwater, adsorbed to soils, volatilized in soil gas, and as a residual and mobile immiscible fluids (Figure 8). Technologies for DNAPL containment are promising but are still a long way before they can be proven in a variety of field situations.

6.2 Continuing Concern for DNAPLs

The potential for extensive contamination of groundwater by dense non-aqueous phase liquids is high because of their widespread production, transport, utilization and disposal. There are many DNAPL contaminated sites in North America, and dissolved constituents derived from DNAPLs are frequently detected in groundwater supplies.

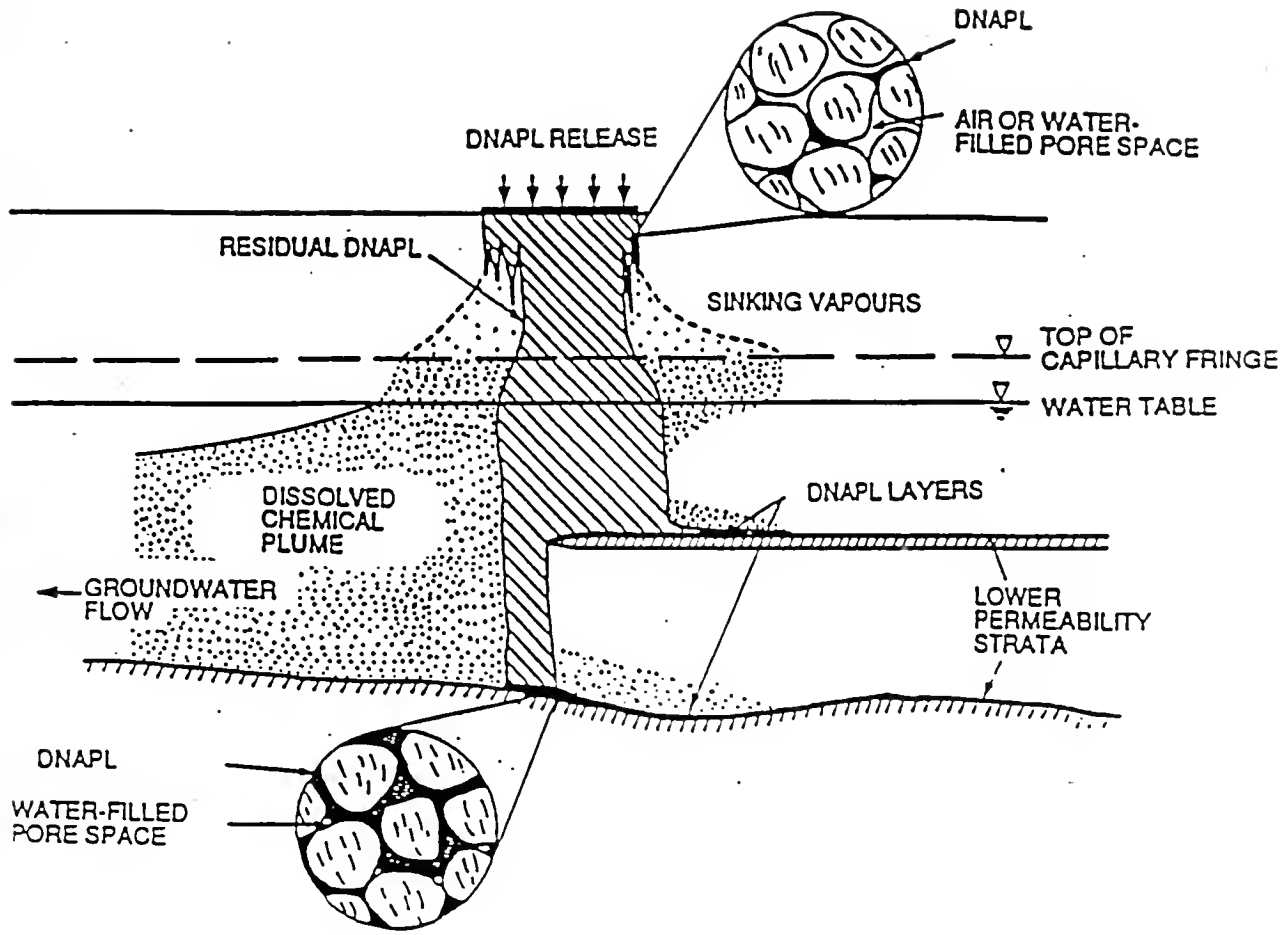


Figure 8. Schematic of the distribution of subsurface contamination emanating from residual DNAPL sources in the vadose and water saturated zones, and DNAPL pools (Feenstra and Cherry, 1990)

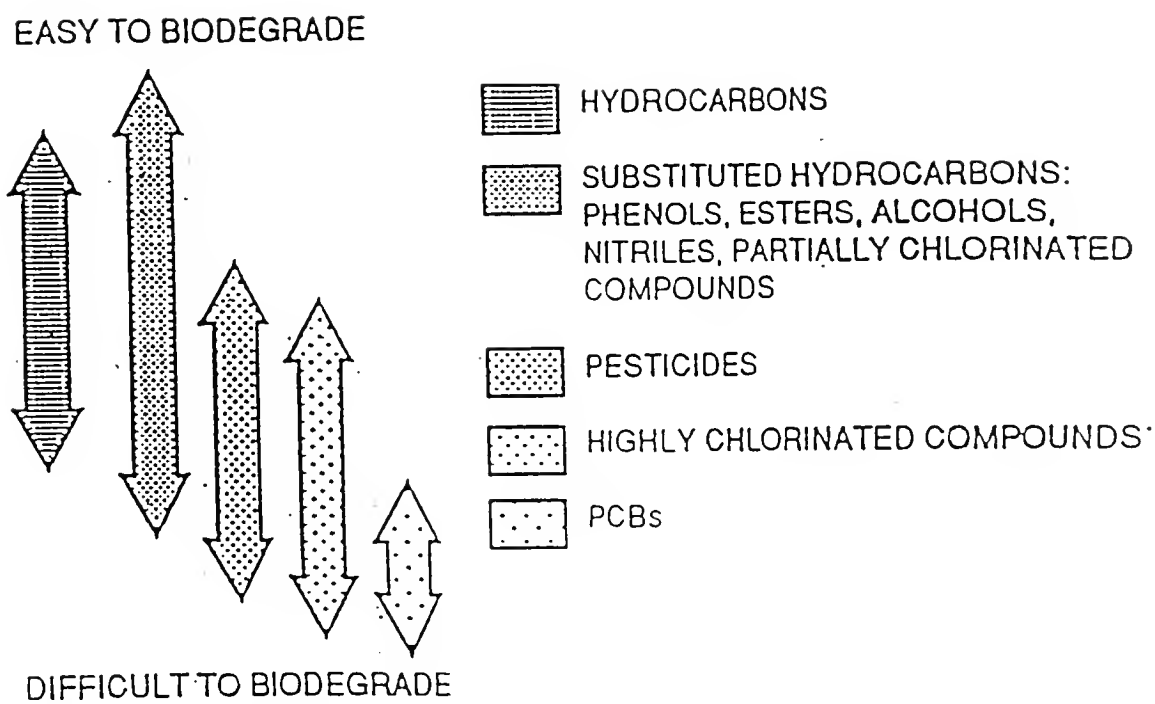
Of the many DNAPLs detected in groundwater chlorinated solvents are the most frequently encountered (e.g. trichloroethylene, tetrachloroethylene and trichloroethene, PCBs, creosote and coal tar). A typical example of DNAPL contamination in Ontario is PCB contamination at Smithville, near Hamilton.

DNAPLs rank very low in degradability when compared to a wide range of other organic contaminants (Figure 9). DNAPL sources and contamination are associated with a wide range of industries and operations, for example:

a) wood treatment operations (creosote);
b) manufactured gas plants (coal tar);
c) transformer oil production, processing, and disposal facilities;
d) chemical industry facilities (chlorinated solvents, pesticides, herbicides etc.)
e) steel industry coking operations (coal tar);
f) dry cleaners (chlorinated solvents);
g) electronic instruments manufacturers (chlorinated solvents);
h) machine shops (chlorinated solvents);
i) print shops (chlorinated solvents);
j) metal works (chlorinated solvents);
k) waste disposal facilities (all types).

6.3 DNAPL Rate of Penetration in the Subsurface

The rate of DNAPL infiltration in the subsurface is greater than generally predicted by soil permeabilities.



Source: Adapted from Retec Inc.

Figure 9
Biodegradability Ranking of Organic Contaminants

Inlaboratory experiments conducted by Schwille, for example, (Schwille 1988), he observed that tetrachloroethane sunk through 2 ft. (61 cm) of variably saturated coarse sand in 10 minutes and through 3 ft.(91 cm) of saturated coarse sand in 60 minutes. At this rate of penetration (with no lateral diversion) it would take, for example, a DNAPL such as TCE approximately 5 hours to penetrate 60 ft (18.3m) of coarse sand in the unsaturated zone.

The actual penetration time will likely be greater because of soil heterogeneities and will vary with soil conditions and DNAPL properties (e.g. density and viscosity). However, the above calculations by Schwille show that for a sufficient volume, DNAPL can reach a relatively deep water table in days or weeks rather than years.

6.4 Treatment Technologies For DNAPL Chemicals

When contamination with DNAPLs is confirmed at a site the scope and complexity of any treatment efforts increase. The four traditional methods of treatment for contaminated groundwater - Pump-and-treat, Vapour extraction, in-situ bioremediation and excavation followed by off-site treatment have proven to be unsatisfactory for treating DNAPL contaminated soils and groundwater. Some of the underlying reasons for such a failure include:

1. Pump-and-treat method can be used to contain the contaminant but may not remediate fully the subsurface due to the low solubility of DNAPLs. Also subsurface heterogeneities limit the ability to move water through many contaminated zones, thereby limit the ability of pump-and-treat systems to properly clean a site.

2. In-situ vapour extraction may be effective to remediate the volatile portions of DNAPL but not the non-volatile ones. The latter would leave residues which are difficult to remove.

3. In-situ bioremediation by itself is normally an effective method of treatment in the aqueous phase where oxidation of the contaminant can occur, but is unlikely to work on DNAPLs. It is also important to note that biodegradability of high molecular weight contaminants (e.g. PCBs) and the high condensed PAHs in creosotes are limited by their low solubility or non-bioavailability.

4. Off-site treatment and/or disposal may be impossible or very costly at many sites due to depths and volume of water involved.

Besides the technologies noted above, several others have been suggested and many more are still on the drawing board. The most promising ones are those known as the emerging technologies. It is not possible to address the efficacy of the emerging or experimental technologies mainly due to the lack of data. The following is a list of some of the concepts under consideration for remediation of DNAPLs:

1. Containment/Restoration;
2. DNAPL recovery methods;
3. Direct and enhanced DNAPL recovery methods:
   a) induced gradient water flooding;
   b) chemically enhanced recovery;
   c) thermally enhanced recovery;
4. Treatment train / Pump and treat.

Interested readers are referred to the list of references in the Bibliography for more details.

6.5 General Remediation Strategy for DNAPL Contaminated Sites

The restoration of ground water to drinking water standards in-situ or ex-situ may prove infeasible at most DNAPL - affected sites largely due to the effects of DNAPL behaviour. In such cases, alternate approach to managing DNAPL problems is needed. A DNAPL contaminated site may be better managed if it is subdivided into at least three zones (Newell et al., 1991) as follows:

a) dissolved phase zone;
b) confirmed free-phase DNAPL zone;
c) potential DNAPL zone (either free-phase or residual DNAPL).

Based on Figure 8, areas, where site data indicate a low probability of DNAPL in the aquifer, would be designated as "dissolved phase zones". In those areas conventional clean-up standards and remediation technologies would be applied.

In areas where the presence of DNAPL is confirmed (e.g. free phase DNAPL exists in monitoring wells), a DNAPL containment strategy could be applied in place of conventional groundwater remediation standards.

7.0 SUMMARY AND CONCLUSIONS

A brief review and description of groundwater treatment technologies has been presented in this report. Some of the technologies discussed are commercially available, others are still at various stages of development. A few have been rigorously tested. Many of these technologies are still subject to intensive field tests. While some can be used independently, many are most effective only when they are used in conjunction with the other technologies.

Groundwater treatment technologies generally fall into two major categories namely:

a) In-situ technologies - these are ones where the treatment process takes place in the subsurface (in place). A typical example of an in-situ remedial technology is in-situ Bioremediation.

b) Ex-situ technologies - these are methods by which contaminated groundwater is treated on the surface. For these treatment methods to be effective the contaminated water must be pumped to the surface, treated and then re-injected back into the aquifer. Examples of ex-situ treatment technologies include Carbon Adsorption.

The treatment of contaminated groundwater requires knowledge of the physical processes (advection, dispersion and diffusion) that affect and control the migration of contaminants in the subsurface. Remedial actions are expensive and the benefits of employing such technologies must be carefully evaluated at sites where a combination of potential risks of exposure and impact to human health and the environment are known to exist.

Available information pertaining to existing and emerging groundwater treatment technologies confirm that there are fewer technologies applicable for the treatment of groundwater as opposed to treatment of soils. The duration for treatment of groundwater is also less predictable. For sites contaminated with numerous types of compounds, e.g VOCs, PCBs, pesticides, metals, a phased approach is recommended. For example, VOCs would be removed first, using say, vacuum extraction then other technologies could be applied on the rest of the waste.

It can be deduced from what we know to-day that the long-term future of groundwater treatment is not certain. This is especially true when it is realized that there is nothing on the horizon to improve the Pump-and-Treat system. However, advances are being made toward improving our understanding of the treatment of contaminated groundwater. Because groundwater contamination varies so greatly from site to site, the few technologies now being developed cannot effectively meet the needs of the many anticipated groundwater treatment projects.

A number of effective technologies have been developed for the treatment groundwater contaminated with soluble constituents e.g Benzene, Toluene, Ethylbenzene and Xylene (BTEX). The struggle for developing effective remedial technologies for groundwater contaminated with DNAPL sources, however, is bound to continue for some time.

A careful review of information on groundwater treatment technologies shows that a wide communication gap exists between the project managers and the research scientists. This gap hinders the badly needed progress in groundwater treatment area and must be narrowed. Information about

groundwater treatment technologies must be better disseminated. The stakeholders in the industry, including the government, should improve the development and diversity of technologies and to do a better job of sharing cost and performance data.

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APPENDIX I

Pump - and - Treat System

APPENDIX I

Pump - and - Treat

Pump-and-treat refers to the extracting of contaminated groundwater and treating it at the surface by any of the number of treatment technologies, including Air Stripping, Carbon adsorption, Catalytic Oxidation, Thermal or Biological treatment. Pump-and-treat systems have been widely used for aquifer remediation for over ten years. The method is used for two main purposes:

1) to remove contaminants from the subsurface for treatment,
2) to maintain gradient control so as to prevent the contaminants from migrating farther from the site.

Certain recent studies have suggested that pump - and- treat procedures may not be as effective as anticipated in restoring aquifers to precontamination conditions (U.S. EPA 1989, 1992, Kent et al 1990). However, in many cases results of using such procedures implied that significant reductions in contaminant levels are possible. A typical example of the success of this procedure has been in Santa Clara Valley, in California where Pump - and- treat has been extensively used over the past several years.

One of the most notable advantages of this method is that conventional methods of wastewater treatment can be employed once the contaminated groundwater is on the surface. The treated water can be discharged to a receiving water body. In general, numerous projects conducted using the pump-and-treat method have results showing rapid removal of chemicals at the beginning of pumping, followed by gradual decrease ending in an asymptote.

The disadvantages of this technology are that it is expensive to design, install and operate; and in all known cases, must be maintained and operated for decades before accurate projections for achievements can be made. Furthermore, although most test results of this method have shown pump-and-treat to be an excellent method to control plume movement, none of these tests could confirm that the site(s) were fully remediated using the technique. As the number of sites with groundwater contamination increases and stricter measures are being imposed by regulatory agencies, the pump-and-treat technology is now under intense scrutiny.

The primary reason for the perceived failure of pump-and-treat is the unrealistic expectation that chemicals that have contaminated an aquifer over the years or decades can be cleaned up to parts per billion concentrations in a short time. Contaminants that have been in the ground for a long period of time have been able to diffuse into the less permeable zones of porous media aquifers and into the bedrock matrix of the fractured rock aquifers (Hoffman, 1993). Pump-and-treat systems are known to be inefficient in removing these contaminants, since the majority of contaminated water removed by pumping will come from the most permeable zones of the aquifer.

Up until the late 1980s the focus of groundwater treatment was on petroleum hydrocarbon contamination; most often resulting from leaking storage tanks. At that time though costly, the problem seemed as though it could be solved with the pump-and-treat method. In early 1990s the focus shifted to chlorinated solvents --- contaminants from synthetic chemicals widely used by industry since 1940s.

Today, the challenge is the non-aqueous phase liquids (NAPLs) and in particular, the DNAPL chemicals. DNAPL sites represent two major forms of contamination 1) the dissolved phase and 2) the immiscible phase. Traditional pump-and-treat technologies are

essentially ineffective in achieving overall groundwater treatment. The method can be used to contain and remove the dissolved phase plume, but removal of the immiscible phase is more difficult to achieve. The recognition of this fact is fuelling tremendous interest in both government and private sectors for innovative technologies to improve the effectiveness of in-situ treatment for contaminated groundwater.

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APPENDIX II

Summary of Treatment Technologies for Contaminated Groundwater

APPENDIX II

SUMMARY OF TREATMENT TECHNOLOGIES FOR CONTAMINATED GROUNDWATER
(Demonstrated[1], Developing[2] and Alternative[3] Technologies)

Technology	Typical Contaminants	Advantages	Limitations	Costs US$/ton
In Situ Bioremediation[1]	VOCs, Phenols Diesel fuel	- low costs - low manpower	- heavy metal - pesticides, other toxics	15 - 60 50 - 100 cdn/ N.Ontario
Vacuum Extraction[1]	VOCs, PCBs	- removes VOCs, semi volatiles and PCBs.	- most effective for highly volatile compounds - rel. low costs	10 - 150
Photochemical Oxidation[1]	VOCs, PCBs	- complete destruction of contaminants. - process flexible - higher initial capital costs	- requires good transmission of UV light. - does not address free product phase	300 - 1,400
Air Stripping[2]	VOCs	- can treat large volumes of water - reliable to meet objectives	- most effective with low level BTEXs	60 - 100 (Capital cost)
Air Sparging[2]	VOCs, PCBs	- low cost - treatment on site	- spread of dissolved contamination	N/A

Technology	Typical Contaminants	Advantages	Limitations	Costs US$/ton
Carbon Adsorption[2]	PAHs, BTEX	- removes dissolved organic compounds	- high opeational costs - pretreatment may be required	15-140
Funnel-and-Gate System[3]	VOCs, PAHs	- no maintenace -in-situ treatment	- hard to monitor	N/A
The Forager Sponge[3]	Heavy Metals	- removes heavy metal ions - strong affinity for metals	- not very effective for chromium	N/A
Microbial "Bio-filter"[3]	gasoline, diesel,	- no nutrients injected	--	N/A
Metal catalysed degradation[3]	TCE,	- uses metal as catalysts - low costs	- toxic break down products - long-term integrity	N/A
'Algasorb"[3]	Heavy metals	- high affinity for metals	--	N/A
Adsorptive Filtration[3]	Metals	- uses conventional sand filter	--	N/A
Bio-Tower[3]	acetone, benzene	-treats influent water, landfill leachate	--	N/A

Technology	Typical Contaminants	Advantages	Limitations	Costs US$/ton
Polymers[3]	BTEX	- removes dissolved organics	- More tests needed --	N/A
Electro-kinetics[3]	Metals	- induces flow rate - an improvement on Pump-and-treat	- rigorous field tests are still required	N/A
Physical Barriers[3]	NAPLs	- reduce flax of contaminants through the wall	- imperfections in wall construction - monitoring	N/A

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[1] For "Demonstrated" technologies - a substantial amount of performance data exists.
[2] "Developing" technologies - require more controlled field studies and large-scale site trials to generate reliable performance data
[3] "Alternative" technologies, show promise, are in development stage and their long-term effectiveness has not yet been demonstrated.

- = not provided by the Company
N/A = information not available

APPENDIX III

Technologies Evaluated under the Superfund Innovative Technology Evaluation (SITE) Program as of October 1994 (EPA/540/R-94/526; Nov. 1994)

APPENDIX IIIa

Completed Demonstration Program Projects as of October 1994

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
Accutech Remedial Systems, Inc., Keyport, NJ (005)* *Demonstration Date:* July - August 1992	Pneumatic Fracturing Extraction** and Catalytic Oxidation/New Jersey Environmental Cleanup Responsibility Act Site in Hillsborough, NJ	John Liskowitz 908-739-6444	Uwe Frank 908-321 6626	Soil, Rock	Not Applicable	Halogenated and Nonhalogenated VOCs and SVOCs
Advanced Remediation Mixing, Inc. (formerly Chemfix Technologies/ CeTech Resources), Kenner, LA (002) *Demonstration Date:* March 1989	Solidification and Stabilization/ Portable Equipment Salvage Company Site in Clackamas, OR	Sam Pizzitola 504-461-0466	Edwin Barth 513-569-7669	Soil, Sludge, Solids, Ash, Electroplating Wastes	Heavy Metals	High Molecular Weight Organics
American Combustion, Inc., Norcross, GA (001) *Demonstration Date:* November 1987 - January 1988	PYRETRON® Thermal Destruction/EPA's Incineration Research Facility in Jefferson, AR using soil from Stringfellow Acid Pit Superfund Site in Glen Avon, CA	Gregory Gitman 404-564-4180	Laurel Staley 513-569-7863	Soil, Sludge, Solid Waste	Not Applicable	Nonspecific Organics
AWD Technologies, Inc., San Francisco, CA (004) *Demonstration Date:* September 1990	Integrated Vapor Extraction and Steam Vacuum Stripping/San Fernando Valley Groundwater Basin Superfund Site in Burbank, CA	David Bluestein 415-227-0822	Gordon Evans 513-569-7684	Groundwater, Soil	Not Applicable	VOCs
Babcock & Wilcox Co.,** Alliance, OH (006) *Demonstration Date:* November 1991	Cyclone Furnace/Developer's Facility in Alliance, OH	Dorothy Haidet 216-829-7395	Laurel Staley 513-569-7863	Solids, Soil, Sludge	Nonspecific, Low-Level Radionuclides	Nonspecific Organics
Bergmann USA, Gallatin, TN (007) *Demonstration Date:* May 1992	Soil and Sediment Washing/ Saginaw Bay Confined Disposal Facility in Saginaw, MI	Richard Traver 615-230-2217	Jack Hubbard 513-569-7507	Soil, Sediment	Heavy Metals	PCBs, Nonspecific Organics

* Solicitation Number

** From Emerging Technology Program

APPENDIX IIIa (continued)

Completed Demonstration Program Projects as of October 1994

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
Berkeley Environmental Restoration Center (formerly Udell Technologies, Inc.), Berkeley, CA (005) *Demonstration Date:* December 1993	In Situ Steam Enhanced Extraction Process/Lawrence Livermore National Laboratory in Altamont Hills, CA	Kent Udell 510-642-2928 Steve Collins 510-643-1300	Paul dePercin 513-569-7797	Soil, Groundwater	Not Applicable	VOCs and SVOCs, Hydrocarbons, Solvents
Billings and Associates, Inc., Albuquerque, NM (007) *Demonstration Date:* March 1993 - May 1994	Subsurface Volatilization and Ventilation System (SVVS®)/ Site in Buchanan, Michigan	Gale Billings 505-345-1116 Don Brenneman 713-575-4693	Paul dePercin 513-569-7797	Soil, Sludge, Groundwater	Not Applicable	BTEX, VOCs, SVOCs
BioGenesis Enterprises, Inc., Springfield, VA (005) *Demonstration Date:* November 1992	BioGenesis™ Soil and Sediment Washing Processes/Refinery Site in Minnesota	Thomas Rougeux 703-913-9700	Annette Gatchett 513-569-7697	Soil	Not Applicable	Volatile and Nonvolatile Hydrocarbons, PCBs
Bio-Rem, Inc., Butler, IN (006) *Demonstration Date:* May 1992 - June 1993	Augmented In Situ Subsurface Bioremediation Process/ Williams AFB in Phoenix, AZ	David Mann 219-868-5823 800-428-4626	Teri Richardson 513-569-7949	Soil, Water	Not Applicable	Hydrocarbons, Halogenated Hydrocarbons, and Chlorinated Compounds
BioTrol, Inc., Eden Prairie, MN (003) *Demonstration Date:* July - September 1989	Biological Aqueous Treatment System/MacGillis and Gibbs Superfund Site in New Brighton, MN	Sandra Clifford 612-942-8032	Mary Stinson 908-321-6683	Liquid Waste, Groundwater	Nitrates	Chlorinated and Nonchlorinated Hydrocarbons, Pesticides
BioTrol, Inc., Eden Prairie, MN (003) *Demonstration Date:* September - October 1989	Soil Washing System/MacGillis and Gibbs Superfund Site in New Brighton, MN	Sandra Clifford 612-942-8032	Mary Stinson 908-321-6683	Soil	Metals	High Molecular Weight Organics, PAHs, PCP, PCBs, Pesticides
Brice Environmental Services Corporation, Fairbanks, AK (006) *Demonstration Date:* September 1992	Soil Washing Plant/Alaskan Battery Enterprises Superfund Site in Fairbanks, AK	Craig Jones 907-452-2512	Hugh Masters 908-321-6678	Soil	Radioactive and Heavy Metals	Not Applicable

APPENDIX IIIa (continued)

Completed Demonstration Program Projects as of October 1994

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
Canonie Environmental Services Corporation, Porter, IN (006) *Demonstration Date:* September 1992	Low Temperature Thermal Aeration (LTTA®)/Pesticide Site in Phoenix, AZ	Thomas Froman 219-926-8651	Paul dePercin 513-569-7797	Soil, Sludge, Sediment	Not Applicable	VOCs, SVOCs, OCPs, OPPs, TPHs
CF Systems Corporation, Woburn, MA (002) *Demonstration Date:* September 1988	Liquified Gas Solvent Extraction (LG-SX) Technology/New Bedford Harbor Superfund Site in New Bedford, MA	Chris Shallice 617-937-0800	Mark Meckes 513-569-7348	Soil, Sludge, Wastewater	Not Applicable	VOCs, SVOCs, PAHs, PCBs, Dioxins, and Pentachlorophenol
COGNIS, Inc.,** Santa Rosa, CA (009)/(E05) *Demonstration Date:* August 1994	Chemical Treatment/Twin Cities Army Ammunition Plant in New Brighton, MN	Bill Fristad 707-576-6235	Michael Royer 908-321-6633	Soil, Sludge, Sediment	Lead, Heavy Metals	Not Applicable
Dehydro-Tech Corporation, East Hanover, NJ (004) *Demonstration Date:* August 1991	Carver-Greenfield Process® for Solvent Extraction of Wet, Oily Wastes/EPA's Research Facility in Edison, NJ	Theodore Trowbridge 201-887-2182	Laurel Staley 513-569-7863	Soil, Sludge, Sediment	Not Applicable	PCBs, Dioxins, Oil-Soluble Organics
E.I. DuPont de Nemours and Co. and Oberlin Filter Co., Newark, DE (003) *Demonstration Date:* April - May 1990	Membrane Microfiltration/ Palmerton Zinc Superfund Site in Palmerton, PA	Ernest Mayer 302-774-2277	John Martin 513-569-7758	Groundwater, Leachate, Wastewater, Electroplating Rinsewaters	Heavy Metals, Cyanide, Uranium	Organic Particulates, Volatile Organics
Dynaphore, Inc., Richmond, VA (006) *Demonstration Date:* April 1994	FORAGER® Sponge/National Lead Industry Site in Pedricktown, NJ	Norman Rainer 804-288-7109	Carolyn Esposito 908-906-6895	Industrial Discharge, Municipal Sewage Process Streams, Acid Mine Drainage Wastes	Metals	Not Applicable

** From Emerging Technology Program

APPENDIX IIIa (continued)

Completed Demonstration Program Projects as of October 1994

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
ECOVA Corporation, Golden, CO (006) *Demonstration Date:* May - September 1991	Bioslurry Reactor/EPA's Test and Evaluation Facility in Cincinnati, OH	William Mahaffey 303-273-7133	Ronald Lewis 513-569-7856	Soil	Not Applicable	Creosote and Petroleum Wastes
ELI Eco Logic International Inc., Rockwood, Ontario, Canada (006) *Demonstration Date:* October - November 1992	Gas-Phase Chemical Reduction Process/Middleground Landfill in Bay City, MI	Jim Nash 519-856-9591	Gordon Evans 513-569-7684	Soil, Sludge, Liquids	Not Applicable	PCBs, PAHs, Chlorinated Dioxins and Dibenzofurans, Chlorinated Solvents and Chlorophenols
ELI Eco Logic International Inc., Rockwood, Ontario, Canada (006) *Demonstration Date:* October - November 1992	Thermal Desorption Unit/ Middleground Landfill in Bay City, MI	Jim Nash 519-856-9591	Gordon Evans 513-569-7684	Soil, Sludge, Liquids	Not Applicable	PCBs, PAHs, Chlorinated Dioxins and Dibenzofurans, Chlorinated Solvents and Chlorophenols
EPOC Water, Inc., Fresno, CA (004) *Demonstration Date:* May - June 1992	Precipitation, Microfiltration, and Sludge Dewatering/Iron Mountain Superfund Site in Redding, CA	Rodney Squires 209-291-8144	Jack Hubbard 513-569-7507	Sludge, Wastewater, Leachable Soil	Heavy Metals	Pesticides, Oil, Grease
Filter Flow Technology, Inc., League City, TX (006) *Demonstration Date:* September 1993	Heavy Metals and Radionuclide Polishing Filter/DOE's Rocky Flats Plant in Denver, CO	Tod Johnson 713-332-3438	Annette Gatchett 513-569-7697	Groundwater, Industrial Wastewater	Heavy Metals, Radionuclides	Not Applicable
Funderburk & Associates (formerly HAZCON, Inc.), (001) *Demonstration Date:* October 1987	Dechlorination and Immobilization/Former Oil Processing Plant in Douglassville, PA	Not Available	Paul dePercin 513-569-7797	Soil, Sludge, Sediment	Heavy Metals	Nonspecific Organics
General Atomics, San Diego, CA (001) *Demonstration Date:* March 1989	Circulating Bed Combustor/Developer's Facility in San Diego, CA using waste from McColl Superfund Site in Fullerton, CA	Jeffrey Broido 619-455-4495	Douglas Grosse 513-569-7844	Soil, Sludge, Slurry, Liquids	Metals, Cyanide	Halogenated and Nonhalogenated Organic Compounds, PCBs

APPENDIX IIIa (continued)

Completed Demonstration Program Projects as of October 1994

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
Geo-Con, Inc. Monroeville, PA (001) (2 Demonstrations) *Demonstration Date:* April - May 1988	In Situ Solidification and Stabilization Process/General Electric Service Shop Site in Hialeah, FL	Chris Ryan or Linda Ward 412-856-7700	Mary Stinson 908-321-6683	Soil, Sediment	Nonspecific Inorganics	PCBs, PCP, Other Nonspecific Organics
Geosafe Corporation, Richland, WA (002) *Demonstration Date:* March - April 1994	In Situ Vitrification/Parsons Chemical Site in Grand Ledge, MI	James Hansen 509-375-0710	Teri Richardson 513-569-7949	Soil, Sludge, Sediments	Nonspecific Inorganics	Nonspecific Organics
GIS/Solutions, Inc., Concord, CA (007) *Demonstration Dates:* August 1993 (CA) and December 1993 (D.C.)	GIS-Key™ Environmental Data Management System/ San Francisco, CA and Washington, D.C.	Charles Tupitza 510-602-9206	Richard Eilers 513-569-7809	Not Applicable	Not Applicable	Not Applicable
GRACE Dearborn Inc., Mississauga, Ontario, Canada (008) *Demonstration Date:* September 1994	DARAMEND™ Bioremediation Technology/Domtar Wood Preserving Site in Trenton, Ontario, Canada	Alan Seech or Igor Marvan 905-279-2222	Teri Richardson 513-569-7949	Soil, Sediment	Not Applicable	PAHs, PCPs, Total Petroleum Hydrocarbons
Gruppo Italimpresse (developed by Shirco Infrared Systems, Inc.), Rome, Italy (001) (2 Demonstrations) *Demonstration Dates:* August 1987 (FL) and November 1987 (MI)	Infrared Thermal Destruction/Peak Oil Superfund Site in Brandon, FL and Rose Township Superfund Site in Oakland County, MI	Rome 011-39-06-8802001 Padova 011-39-049-773490	Laurel Staley 513-569-7863	Soil, Sediment	Not Applicable	Nonspecific Organics
High Voltage Environmental Applications, Inc. (formerly Electron Beam Research Facility, Florida International University, and University of Miami),** Miami, FL (008)/(E03) *Demonstration Date:* September 1994	High-Energy Electron Irradiation/DOE's Savannah River Site in Aiken, SC	William Cooper 305-593-5330	Franklin Alvarez 513-569-7631	Water Streams, Sludge	Not Applicable	Most Organics

** From Emerging Technology Program

APPENDIX IIIa (continued)

Completed Demonstration Program Projects as of October 1994

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
Horsehead Resource Development Co., Inc., Monaca, PA (004) *Demonstration Date:* March 1991	Flame Reactor/Developer's Facility in Monaca, PA using waste from National Smelting and Refining Company Superfund Site in Atlanta, GA	Regis Zagrocki 412-773-2289	Donald Oberacker 513-569-7510 Marta K. Richards 513-569-7692	Soil, Sludge, Industrial Solid Residues	Metals	Not Applicable
Hrubetz Environmental Services, Inc., Dallas, TX (007) *Demonstration Date:* January - February 1993	HRUBOUT® Process/Kelly Air Force Base in San Antonio, TX	Michael Hrubetz or Barbara Hrubetz 214-363-7833	Gordon Evans 513-569-7684	Soil	Not Applicable	Halogenated or Nonhalogenated Volatiles or Semivolatiles
Hughes Environmental Systems, Inc., (005) *Demonstration Date:* August 1991 - September 1993	Steam Enhanced Recovery Process/Fuel Spill Site in Huntington Beach, CA	Not Available	Paul dePercin 513-569-7797	Soil, Groundwater	Not Applicable	VOCs and SVOCs
IIT Research Institute/Brown and Root Environmental, Chicago, IL/Oak Ridge, TN (007) *Demonstration Date:* August 1993	Radio Frequency Heating/Kelly Air Force Base in San Antonio, TX	Harsh Dev 312-567-4257 Paul Carpenter 904-283-6187 Clifton Blanchard 615-483-9900	Laurel Staley 513-569-7863	Soil	Not Applicable	Petroleum Hydrocarbons, VOCs, SVOCs
KAI Technologies, Inc./Brown and Root Environmental, Woburn, MA/Oak Ridge, TN (008) *Demonstration Date:* January - March 1994	Radio Frequency Heating/Kelly Air Force Base in San Antonio, TX	Raymond Kasevich 617-932-3328 Paul Carpenter 904-283-6187 Clifton Blanchard 615-483-9900	Laurel Staley 513-569-7863	Soil	Not Applicable	Petroleum Hydrocarbons, VOCs, SVOCs
Magnum Water Technology, El Segundo, CA (007) *Demonstration Date:* March 1993	CAV-OX® Process/Edwards Air Force Base, CA	Dale Cox 310-322-4143 Jack Simser 310-640-7000	Richard Eilers 513-569-7809	Groundwater, Wastewater	Not Applicable	Halogenated Solvents, Phenol, Pentachlorophenol, PCBs, BTEX
Maxymillian Technologies, Inc. (formerly Clean Berkshires Inc.), Pittsfield, MA (008) *Demonstration Date:* November - December 1993	Mobile Thermal Desorption System/Niagara Mohawk Power Corporation's Harbor Point Site in Utica, NY	James Maxymillian 413-499-3050 Neal Maxymillian 617-695-9770 800-695-7771	Ronald Lewis 513-569-7856	Soil	Cyanide	VOCs, SVOCs, PAHs, and Coal Tars

APPENDIX IIIa (continued)

Completed Demonstration Program Projects as of October 1994

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
North American Technologies Group, Inc., Sacramento, CA (008) *Demonstration Date:* June 1994	Oleophilic Amine-Coated Ceramic Chip/Petroleum Products Corporation Site in Fort Lauderdale, FL	Cathryn Wimberly 916-366-6165	Laurel Staley 513-569-7863	Groundwater, Marine Wastes	Not Applicable	Gasoline, Crude Oil, Diesel Fuel, BTEX, PAHs, PCBs,PCP, Trichloroethene
NOVATERRA, Inc. (formerly Toxic Treatments USA, Inc.), Los Angeles, CA (003) *Demonstration Date:* September 1989	In Situ Steam and Air Stripping/Annex Terminal in San Pedro, CA	Philip LaMori 310-843-3190	Paul dePercin 513-569-7797	Soil	Nonspecific Inorganics, Heavy Metals	VOCs, SVOCs, Hydrocarbons
Resources Conservation Company, Ellicott City, MD (001) *Demonstration Date:* July 1992	B.E.S.T. Solvent Extraction Technology/Grand Calumet River Site in Gary, IN	Lanny Weimer 410-596-6066	Mark Meckes 513-569-7348	Soil, Sludge, Sediment	Not Applicable	Oil, PCBs, PAHs, Pesiticides, Herbicides
Retech, Inc., Ukiah, CA (002) *Demonstration Date:* July 1991	Plasma Arc Vitrification/DOE's Component Development and Integration Facility in Butte, MT	Ronald Womack or Leroy Leland 707-462-6522	Laurel Staley 513-569-7863	Soil, Sludge	Metals	Nonspecific Organics
Risk Reduction Engineering Laboratory, Cincinnati, OH (005) *Demonstration Date:* August - September 1993	Base-Catalyzed Decomposition Process/Koppers Company Superfund Site in Morrisville, NC	Carl Brunner 513-569-7655 Yei-Shong Shieh or G. Steven Detwiler 610-832-0700	Terrence Lyons 513-569-7589	Soil, Sediment, Sludge	Not Applicable	PCBs, PCPs, Halogenated Compounds
Risk Reduction Engineering Laboratory, Cincinnati, OH (007) *Demonstration Date:* November 1992	Volume Reduction Unit/ Escambia Treating Company Site in Pensacola, FL	Richard Griffiths 908-321-6629	Teri Richardson 513-569-7949	Soil	Metals	Creosote, PCPs, PAHs, VOCs, SVOCs, Pesticides
Risk Reduction Engineering Laboratory and IT Corporation, Cincinnati, OH (004) *Demonstration Dates:* September 1988 (MI), December 1989 (KY), and August 1990 (GA)	Debris Washing System/ Superfund Sites in Detroit, MI; Hopkinsville, KY; and Walker County, GA	Michael Taylor or Majid Dosani 513-782-4700	Donald Sanning 513-569-7875	Debris	Nonspecific Inorganics	Nonspecific Organics, PCBs, Pesticides

APPENDIX IIIa (continued)

Completed Demonstration Program Projects as of October 1994

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
Risk Reduction Engineering Laboratory and USDA Forest Products Laboratory, Cincinnati, OH/Madison, WI (006) *Demonstration Date:* June - November 1992	Fungal Treatment Technology/ Brookhaven Wood Preserving Site in Brookhaven, MS	John Glaser 513-569-7568 Richard Lamar 608-231-9469	Teri Richardson 513-569-7949	Soil	Not Applicable	PCPs, PAHs, Chlorinated Organics
Risk Reduction Engineering Laboratory, University of Cincinnati, and FRX, Inc., Cincinnati, OH (005) *Demonstration Dates:* July 1991 - September 1992 (IL) and August 1991 - September 1992 (OH)	Hydraulic Fracturing/Xerox Corporation Site in Oak Brook, IL and an underground storage spill site in Dayton, OH	William Slack 513-556-2526	Michael Roulier 513-569-7796	Soil, Groundwater	Nonspecific Inorganics	Nonspecific Organics
Rochem Separation Systems, Inc., Torrance, CA (006) *Demonstration Date:* August 1994	Rochem Disc Tube™ Module System/Central Landfill Superfund Site in Johnston, RI	David LaMonica 310-370-3160	Douglas Grosse 513-569-7844	Liquids	Nonspecific Inorganics	Organic Solvents
RUST Remedial Services, Inc. (formerly offered by Chemical Waste Management, Inc.), Palos Heights, IL (004) *Demonstration Date:* May 1992	X*TRAX™ Thermal Desorption/ Re-Solve, Inc., Superfund Site in North Dartmouth, MA	Chetan Trivedi 708-361-7520 708-361-8400	Paul dePercin 513-569-7797	Soil, Sediment, Sludge	Heavy Metals	VOCs, SVOCs, PCBs, Dioxins
SBP Technologies, Inc., Baton Rouge, LA (005) *Demonstration Date:* October 1991	Membrane Filtration and Bioremediation/American Creosote Works in Pensacola, FL	Clayton Page 504-753-5255	John Martin 513-569-7758	Groundwater, Surface Water, Storm Water, Landfill Leachates, Industrial Process Wastewater	Not Applicable	Organic Compounds, PAHs, PCBs, TCE, PCP

APPENDIX IIIa (continued)

Completed Demonstration Program Projects as of October 1994

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
J R. Simplot,** Pocatello, ID (006) (2 Demonstrations) *Demonstration Dates:* July 1993 (WA) and September 1993 - February 1994 (MO)	The SABRE™ Process/Bowers Field in Ellensburg, WA and Weldon Spring Ordinance Works Site in Weldon Spring, MO	Russel Kaake 208-234-5367	Wendy Davis-Hoover 513-569-7206	Soil	Not Applicable	Nitroaromatics
SoilTech ATP Systems, Inc., Porter, IN (005) (2 Demonstrations) *Demonstration Date:* May 1991 (NY); June 1992 (IL)	Anaerobic Thermal Processor/ Wide Beach Superfund Site in Brant, NY and Waukegan Harbor Superfund Site in Waukegan, IL	Alistair Montgomery 303-790-1747 Joseph Hutton 219-929-4343	Paul dePercin 513-569-7797	Soil, Sludge, Refinery Wastes	Not Applicable	PCBs, Chlorinated Pesticides, VOCs, SVOCs
Soliditech, Inc. (002) *Demonstration Date:* December 1988	Solidification and Stabilization/ Imperial Oil Company/ Champion Chemical Company Superfund Site in Morganville, NJ	Not Available	Jack Hubbard 513-569-7507	Soil, Sludge	Metals, Nonspecific Inorganics	Nonspecific Organics, Oil, Grease
Sonotech, Inc., Atlanta, GA (007) *Demonstration Date:* May - July 1994	Frequency-Tunable Pulse Combustion System/EPA's Incineration Research Facility in Jefferson, AR	Zin Plavnik 404-525-8530	Marta K. Richards 513-569-7692	Soil, Medical Waste	Nonspecific Inorganics	Nonspecific Organics
STC Omega, Inc. (formerly Silicate Technology Corporation), Scottsdale, AZ (003) *Demonstration Date:* November 1990	Chemical Fixation/Solidification Treatment Technologies/Selma Pressure Treating Superfund Site in Selma, CA	Stephen Pelger or Scott Larsen 602-948-7100	Edward Bates 513-569-7774	Soil, Sludge, Wastewater	Metals, Cyanide, Fluorides, Arsenates, Chromates, Selenium	High Molecular Weight Organics, PAHs
Terra-Kleen Response Group, Inc., Oklahoma City, OK (006) *Demonstration Date:* May - June 1994	Solvent Extraction Treatment System/Naval Air Station North Island in San Diego, CA	Alan Cash 405-728-0001	Mark Meckes 513-569-7348	Soil, Sludge, Sediment, Debris	Not Applicable	PCBs, PCP, PAH, Creosote, Chlorinated Pesticides, PCDD, PCDF

** From Emerging Technology Program

APPENDIX IIIa (continued)

Completed Demonstration Program Projects as of October 1994

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
Terra Vac, Inc., San Juan, PR (001) *Demonstration Date:* December 1987 - April 1988	In Situ Vacuum Extraction/ Groveland Wells Superfund Site in Groveland, MA	James Malot 809-723-9171	Mary Stinson 908-321-6683	Soil	Not Applicable	VOCs
Texaco Inc., White Plains, NY (006) *Demonstration Date:* January 1994	Entrained-Bed Gasification/ Developer's Montebello Research Laboratory using a mixture of soil from the Purity Oil Sales Superfund Site in Fresno, CA	Richard Zang 914-253-4047	Marta K. Richards 513-569-7692	Soil, Sludge, Sediment	Nonspecific Inorganics	Nonspecific Organics
Toronto Harbour Commission, Toronto, Ontario, Canada (006) *Demonstration Date:* April - May 1992	Soil Recycling/Toronto Port Industrial District in Toronto, Ontario, Canada	Carol Moore 416-863-2071	Teri Richardson 513-569-7949	Soil	Nonspecific Inorganics	Nonspecific Organics
Ultrox, A Division of Zimpro Environmental, Inc., Santa Ana, CA (003) *Demonstration Date:* March 1989	Ultraviolet Radiation and Oxidation/Lorentz Barrel and Drum Company in San Jose, CA	David Fletcher 714-545-5557	Norma Lewis 513-569-7665	Groundwater, Leachate, Wastewater	Not Applicable	Halogenated Solvents, VOCs, Pesticides, PCBs, BTEX
United States Environmental Protection Agency, San Francisco, CA (007) *Demonstration Date:* June - July 1990	Excavation Techniques and Foam Suppression Methods/ McColl Superfund Site in Fullerton, CA	John Blevins 415-774-2400	Jack Hubbard 513-569-7507	Soil	Not Applicable	VOCs
Vulcan Peroxidation Systems, Inc. (formerly Peroxidation Systems, Inc.), Tucson, AZ (006) *Demonstration Date:* September 1992	**perox-pure™** Chemical Oxidation Technology/Lawrence Livermore National Laboratory in Altamont Hills, CA	Chris Giggy 602-790-8383	Norma Lewis 513-569-7665	Groundwater, Wastewater	Not Applicable	Fuel Hydrocarbons, Chlorinated Solvents, PCBs, VOCs, SVOCs
WASTECH Inc., Oak Ridge, TN (004) *Demonstration Date:* August 1991	Solidification and Stabilization/ Robins Air Force Base in Warner Robins, GA	Benjamin Peacock 615-483-6515	Terrence Lyons 513-569-7589	Soil, Sludge, Liquid Waste	Nonspecific Radioactive Inorganics	Nonspecific Organics

APPENDIX IIIa (continued)

Completed Demonstration Program Projects as of October 1994

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
Roy F. Weston, Inc., West Chester, PA (006) *Demonstration Date:* November - December 1991	Low Temperature Thermal Treatment (LT³®) System/ Anderson Development Company Superfund Site in Adrian, MI	Mike Cosmos 610-701-7423	Paul dePercin 513-569-7797	Soil, Sludge	Not Applicable	VOCs, SVOCs, Petroleum Hydrocarbons, PAHs
Roy F. Weston, Inc./IEG Technologies, Woodland Hills, CA/Charlotte, NC (008) *Demonstration Date:* May 1993 - May 1994	UVB - Vacuum Vaporizing Well/March Air Force Base, CA	Jeff Bannon 818-596-6900 Eric Klingel 704-357-6090	Michelle Simon 513-569-7469	Groundwater	Heavy Metals	VOCs, SVOCs
Wheelabrator Clean Air Systems, Inc. (formerly Chemical Waste Management, Inc.), Schaumburg, IL (005) *Demonstration Date:* September 1992	PO*WW*ER™ Technology/ Chemical Waste Management's Facility in Lake Charles, LA	Annamarie Connolly 708-706-6900	Randy Parker 513-569-7271	Wastewater, Leachate, Groundwater	Metals, Volatile Inorganic Compounds, Salts, Radionuclides	VOCs and Nonvolatile Organic Compounds

APPENDIX IIIb

Ongoing Demonstration Program Projects as of October 1994

APPENDIX IIIb

On-going Demonstration Program Projects as of October 1994

Developer	Technology	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
Accutech Remedial Systems, Inc.,* Keyport, NJ (005)**	Pneumatic Fracturing Extraction** and Catalytic Oxidation	John Liskowitz 908-739-6444	Uwe Frank 908-321-6626	Soil, Rock	Not Applicable	Halogenated and Nonhalogenated VOCs and SVOCs
AlliedSignal Environmental Systems and Services, Des Plaines, IL (003)	Immobilized Cell Bioreactor Biotreatment System	F. Stephen Lupton 708-391-3224 Conrad Kempton 201-455-5531	Ronald Lewis 513-569-7856	Groundwater, Wastewater	Not Applicable	Readily Biodegradable Organic Compounds, PAHs, Diesel Fuel, Chlorobenzene
Andco Environmental Processes, Inc., Buffalo, NY (007)	Electrochemical In Situ Chromate Reduction and Heavy Metal Immobilization	Michael Laschinger 716-691-2100	Douglas Grosse 513-569-7844	Groundwater	Heavy Metals, Hexavalent Chromium	Not Applicable
Aprotek, Sacramento, CA (008)	Ion Conduction Agglomeration System	Cathryn Wimberly 916-366-6165	Jack Hubbard 513-569-7507	Groundwater, Wastewaster, Mining Effluents	Metals	Not Applicable
ASI Environmental Technologies, Inc./ Dames & Moore, Brandon, FL (005)	Hydrolytic Terrestrial Dissipation	Stoddard Pickrell 813-653-3376	Ronald Lewis 513-569-7856	Soil	Not Applicable	Toxaphene and Other Pesticides
BioGenesis Enterprises, Inc.,* Springfield, VA (009)	BioGenesis** Soil and Sediment Washing Process	Thomas Rougeux 703-913-9700	Annette Gatchett 513-569-7697	Soil	Not Applicable	Volatile and Nonvolatile Hydrocarbons, PCBs
CF Systems Corporation,* Woburn, MA (008)	Liquified Gas Solvent Extraction (LG-SX) Technology	Chris Shallice 617-937-0800	Mark Meckes 513-569-7348	Soil, Sludge, Wastewater	Not Applicable	VOCs, SVOCs, PAHs, PCBs, Dioxins, Pentachlorophenol
Colorado Department of Public Health and Environment (developed by Colorado School of Mines),*** Denver, CO (005)/(E01)	Wetlands-Based Treatment	Rick Brown 303-692-3383	Edward Bates 513-569-7774	Acid Mine Drainage	Metals	Not Applicable

* An additional demonstration is planned for this technology. Refer to the profile in the Demonstration Program (completed projects) section for more information.

** Solicitation Number

*** From Emerging Technology Program

APPENDIX IIIb (continued)

On-going Demonstration Program Projects as of October 1994

Developer	Technology	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
EET, Inc., Bellaire, TX (009)	Extraction of PCBs from Porous Surfaces Using the TECHXTRACT™ Process	Tim Tarrillion 713-662-0727	Richard Eilers 513-569-7809	Solids	Heavy Metals, Radionuclides	PCBs, Hydrocarbons
Electrokinetics Inc.,*** Baton Rouge, LA (009)/(E03)	Electro-Klean™ Electrokinetic Soil Processing	Yalcin Acar and Robert Marks 504-388-3992	Randy Parker 513-569-7771	Soil	Heavy Metals and Other Inorganics, Radionuclides	Nonspecific Organics
EnviroMetal Technologies Inc., Guelph, Ontario, Canada (008)	In Situ Metal Enhanced Abiotic Degradation of Dissolved Halogenated Organic Compounds in Groundwater	John Vogan 519-824-0432	Chien Chen 908-906-6985	Groundwater	Not Applicable	Halogenated Organic Compounds
GEOCHEM, A Division of Terra Vac, Lakewood, CO (007)	In Situ Remediation of Chromium in Groundwater	Jim Rouse 303-988-8902	Douglas Grosse 513-569-7844	Groundwater	Hexavalent Chromium, Uranium, Selenium, Arsenic	Not Applicable
Horsehead Resource Development Co., Inc.,* Monaca, PA (008)	Flame Reactor	Regis Zagrocki 412-773-2289	Donald Oberacker 513-569-7510 Marta K. Richards 513-569-7692	Soil, Sludge, Industrial Solid Residues	Metals	Not Applicable
Hydrologics, Inc., Englewood, CO (008)	CURE® - Electrocoagulation Wastewater Treatment System	Carl Dalrymple 303-761-6960	Annette Gatchett 513-569-7697	Water	Aluminum, Arsenic, Barium, Cadmium, Chromium, Cyanide, Lead, Nickel, Uranium, and Zinc	Not Applicable
IT Corporation, San Bernardino, CA (007)	In Situ Groundwater Treatment System	Walter Grinyer 909-799-6869	Michelle Simon 513-569-7469	Groundwater	Not Applicable	VOCs
Matrix Photolytic Inc. (formerly Nutech Environmental),*** London, Ontario, Canada (009)/(E05)	Photocatalytic Water Treatment	Bob Henderson 519-660-8669	Richard Eilers 513-569-7809	Wastewater, Groundwater, Process Water	Nonspecific Inorganics	PCBs, PCDDs, PCDFs, Chlorinated Alkenes, Chlorinated Phenols

* An additional demonstration is planned for this technology. Refer to the profile in the Demonstration Program (completed projects) section for more information.

*** From Emerging Technology Program

APPENDIX IIIb (continued)

On-going Demonstration Program Projects as of October 1994

Developer	Technology	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
Morrison Knudsen Corporation/ Spetstamponazhgeologia Enterprises (STG), Boise, ID (009)	High Clay Grouting Technology	Kathryn Levihn or R Mac Hartley 208-386-6115	Jack Hubbard 513-569-7507	Groundwater	Heavy Metals	Nonspecific Organics
New York State Department of Environmental Conservation, Albany, NY (009)	Multi-Vendor Bioremediation	Nick Kolak 518-485-8792	Annette Gatchett 513-569-7697	Soil	Not Applicable	VOCs
North American Technologies Group, Inc., Sacramento, CA (008)	BioTreat™ System	Cathryn Wimberly 916-366-6165	Mary Stinson 908-321-6683	Soil, Sludge, Mixed Media	Not Applicable	Gasoline, Jet Fuel, Diesel Fuel, Motor Oil, Crude Oil, PAHs, BTEX, Methyl Isobutyl Ketone, TCE, PCP, Creosotes
Pintail Systems Incorporated, Aurora, CO (009)	Spent Ore Bioremediation Process	Leslie Thompson 303-367-8843	Jack Hubbard 513-569-7507	Spent Ore Heaps, Waste Rock Dumps, Mine Tailings, Process Water	Cyanide	Not Applicable
Praxis Environmental Technologies, Inc., Burlingame, CA (008)	In Situ Thermal Extraction Process	Lloyd Stewart 415-548-9288 Paul Carpenter 904-283-6187	Paul dePercin 513-569-7797	Soil, Groundwater	Not Applicable	VOCs and SVOCs, Hydrocarbons, Solvents
Process Technologies, Inc., Boise, ID (009)	Photolytic Destruction for SVE Off-Gases	Mike Swan 208-385-0900 Steve Hodge 916-643-0830	Laurel Staley 513-569-7863	Air, Gases	Not Applicable	VOCs, Chlorinated VOCs, CFCs
Purus, Inc., San Jose, CA (006)	PurCycle™ Vapor Treatment Process	Bart Mass 408-955-1000	Norma Lewis 513-569-7665	Soil, Groundwater, Air	Not Applicable	Fuel Hydrocarbons, VOCs, SVOCs, Chlorinated Solvents
Remediation Technologies, Inc., Seattle, WA (002)	Liquid and Solids Biological Treatment	Merv Cooper 206-624-9349	Ronald Lewis 513-569-7856	Soil, Sediment, Sludge	Not Applicable	Biodegradable Organics, Creosote, PCP, PAHs

APPENDIX IIIb (continued)

On-going Demonstration Program Projects as of October 1994

Developer	Technology	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
Risk Reduction Engineering Laboratory,* Cincinnati, OH (009)	Base-Catalyzed Decomposition Process	Carl Brunner 513-569-7655 Yei-Shong Shieh or G. Steven Detwiler 610-832-0700	Terrence Lyons 513-569-7589	Soil, Sediment, Sludge	Not Applicable	PCBs, PCPs, Halogenated Compounds
Risk Reduction Engineering Laboratory, Cincinnati, OH (006)	Bioventing	Paul McCauley 513-569-7444	Jack Hubbard 513-569-7507	Soil	Not Applicable	Biodegradable Organics
RKK, Ltd., Arlington, WA (009)	CYROCELL™	Christopher Reno 206-653-4844	Annette Gatchett 513-569-7697	Soil, Groundwater, Leachate	Non-specific Inorganics	Non-specific Organics
Sandia National Laboratory,**** Albuquerque, NM (009)	Electrokinetic Extraction in Unsaturated Soils	Eric Lindgren 505-844-3820	Randy Parker 513-569-7271	Soil	Hexavalent Chromium	Not Applicable
Separation and Recovery Systems, Inc., Irvine, CA (002)	SAREX Chemical Fixation Process	Brad Miller 714-261-8860	Jack Hubbard 513-569-7507	Soil, Sludge	Low-Level Metals	Nonspecific Organics
Sevenson Environmental Services, Inc., Munster, IN (009)	MAECTITE® Chemical Treatment Process	Karl Yost 219-836-0116	Jack Hubbard 513-569-7507	Soil, Sludge, Sediment, Solids	Lead, Other Heavy Metals	Not Applicable
SIVE Services, Dixon, CA (009)	Steam Injection and Vacuum Extraction-Linear Flow (SIVE-LF) Process	Douglas Dieter 916-678-8358	Michelle Simon 513-569-7469	Soil	Not Applicable	VOCs, SVOCs
TechTran Environmental, Inc., Houston, TX (005)	Combined Chemical Precipitation, Physical Separation, and Binding Process for Radionuclides and Heavy Metals	E.B. (Ted) Daniels 713-680-8833	Annette Gatchett 513-569-7697	Water, Soil, Sludge	Heavy Metals, Radionuclides	Not Applicable
TriWaste Reduction Services, Inc.,**** Calgary, Alberta, Canada (009)	Thermal Phase Separator and TRACE Soil Washing Unit	Phil Carson 403-234-3229	Gordon Evans 513-569-7684	Soil	Copper, Lead, Zinc	Chlorinated Compounds, PCBs, Hydrocarbons

* An additional demonstration is planned for this technology. Refer to the profile in the Demonstration Program (completed projects) section for more information.

*** From Emerging Technology Program

**** This technology is not profiled in this document. For further information, please contact the Technology Contact or the EPA Project Manager.

APPENDIX IIIb (continued)

On-going Demonstration Program Projects as of October 1994

Developer	Technology	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
Vortec Corporation,*** Collegeville, PA (009)/(E04)	Oxidation and Vitrification Process	James Hnat 610-489-2255	Teri Richardson 513-569-7949	Soil, Sludge, Sediment, Mill Tailings	Metals, Other Nonspecific Inorganics	Nonspecific Organics
Western Research Institute,*** Laramie, WY (005)/(E01)	Contained Recovery of Oily Wastes (CROW™)	Lyle Johnson 307-721-2281	Eugene Harris 513-569-7862	Soil, Water	Not Applicable	Coal Tar Derivatives, Petroleum By-products, PCP
Wheelabrator Technologies Inc., Hampton, NH (008)	WES-PHix Stabilization Process	Mark Lyons 603-929-3000	Chien Chen 908-321-6985	Municipal Waste Combustion Ash, Soil, Sludge	Heavy Metals, Lead, Cadmium, Copper, Zinc	Not Applicable
Xerox Corporation, Webster, NY (009)	Two-Phase Extraction Process	Ron Hess 716-422-3694 Bud Hoda 916-643-1742	Laurel Staley 513-569-7863	Groundwater, Soil	Not Applicable	VOCs
Zenon Environmental Inc.,*** Burlington, Ontario, Canada (007)/(E02)	Cross-Flow Pervaporation System	Philip Canning 905-639-6320	Ronald Turner 513-569-7775	Groundwater, Lagoons, Leachate, Rinsewater	Not Applicable	Solvents, Degreasers, Gasoline, VOCs
Zenon Environmental Inc., Burlington, Ontario, Canada (007)	ZenoGem™ Process	Tony Tonelli 905-639-6320	Daniel Sullivan 908-321-6677	Groundwater, Leachate	Not Applicable	Nonspecific Biodegradable Organics
Zimpro Environmental, Inc., Rothschild, WI (002)	PACT® Wastewater Treatment System	William Copa 715-359-7211	John Martin 513-569-7758	Groundwater, Industrial Wastewater, Leachate	Not Applicable	Biodegradeable VOCs and SVOCs

APPENDIX IIIc

Completed Emerging Program Projects as of October 1994

APPENDIX IIIc

Completed Emerging Technology Program Projects as of October 1994

Developer	Technology	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
ABB Environmental Services, Inc., Wakefield, MA (E03)*	Two-Zone, Plume Interception, In Situ Treatment Technology	Jaret Johnson 617-245-6606	Ronald Lewis 513-569-7856	Groundwater, Wastewater, Soil	Inorganic Chloride	Chlorinated and Nonchlorinated Solvents
AEA Technology, National Environmental Technology Centre (formerly Warren Spring Laboratory), Abingdon, England (E04)	Soil Separation and Washing Process	Peter Wood 011-44-235-463194	Mary Stinson 908-321-6683	Soil, Sludge, Sediment	Metals	Petroleum Hydrocarbons, PAHs
Allis Mineral Systems, Waukesha, WI (E03)	PYROKILN THERMAL ENCAPSULATION Process	John Lees 414-798-6265 Glenn Heian 414-762-1190	Marta K. Richards 513-569-7692	Soil, Sludge	Most Metallic Compounds	Halogenated and Nonhalogenated Organics, Petroleum Products
Aluminum Company of America (formerly ALCOA Separation Technology, Inc.),** Pittsburgh, PA (E03)	Bioscrubber	Paul Liu 412-826-3711	Paul dePercin 513-569-7797	Airstreams from Soil, Water, and Air Decontamination Processes	Not Applicable	Most Volatile Organics
ART International, Inc. (formerly Enviro-Sciences, Inc.), Denville, NJ (E03)	Low-Energy Extraction Process	Werner Steiner 201-627-7601	Jack Hubbard 513-569-7507	Soil, Sludge, Sediment	Not Applicable	Tar, Creosote, PCBs, Chlorinated Hydrocarbons, PAHs, Pesticides
Atomic Energy of Canada, Limited, Chalk River, Ontario, Canada (E01)	Chemical Treatment and Ultrafiltration	Leo Buckley 613-584-3311 Phil Campbell 800-872-2325	John Martin 513-569-7758	Groundwater, Leachate, Wastewater	Heavy Metals	Not Applicable
Babcock & Wilcox Co.,** Alliance, OH (E02)	Cyclone Furnace	Dorothy Haidet 216-829-7395	Laurel Staley 513-569-7863	Solids, Soil, Sludge	Heavy Metals, Radlonuclides	Nonspecific Organics
Battelle Memorial Institute, Columbus, OH (E01)	In Situ Electroacoustic Soil Decontamination	Satya Chauhan 614-424-4812	Jonathan Herrmann 513-569-7839	Soil	Nonspecific Metals	Nonspecific Hydrocarbons
Bio-Recovery Systems, Inc.,** Las Cruces, NM (E01)	Biological Sorption	Mike Hosea 505-523-0405 800-697-2001	Ronald Lewis 513-569-7856	Groundwater, Leachate, Wastewater	Heavy Metals, Uranium	Not Applicable

* Solicitation Number
** Invited to participate in the SITE Demonstration Program

APPENDIX IIIc (continued)

Completed Emerging Technology Program Projects as of October 1994

Developer	Technology	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
BioTrol, Inc., Eden Prairie, MN (E03)	Methanotrophic Bioreactor System	Durrell Dobbins 612-942-8032	David Smith 303-293-1475	Water	Not Applicable	Halogenated Hydrocarbons
Center for Hazardous Materials Research, Pittsburgh, PA (E03)	Acid Extraction Treatment System	Stephen Paff 412-826-5321	George Moore 513-569-7991	Soil	Heavy Metals	Not Applicable
Center for Hazardous Materials Research, Pittsburgh, PA (E04)	Smelting Lead-Containing Waste	Stephen Paff 412-826-5321	Laurel Staley 513-569-7863	Solids, Lead-Containing Waste	Lead	Not Applicable
Cognis, Inc.,** Santa Rosa, CA (E05)	Chemical Treatment	Bill Fristad 707-576-6235	Michael Royer 908-321-6633	Soil, Sludge, Sediment	Heavy Metals, Lead	Not Applicable
Colorado School of Mines,** Golden, CO (E01)	Constructed Wetlands-Based Treatment	Thomas Wildeman 303-273-3642	Edward Bates 513-569-7774	Acid Mine Drainage	Metals	Not Applicable
Electrokinetics Inc.,** Baton Rouge, LA (E03)	Electro-Klean™ Electrokinetic Soil Processing	Yalcin Acar and Robert Marks 504-388-3992	Randy Parker 513-569-7271	Soil	Heavy Metals and Other Inorganics, Radionuclides	Nonspecific Organics
Electron Beam Research Facility, Florida International University, and University of Miami,** Miami, FL (E03)	High-Energy Electron Irradiation	William Cooper 305-348-3049 Charles Kurucz 305-284-6595 Thomas Waite 305-593-5330	Franklin Alvarez 513-569-7631	Water Streams, Sludge	Not Applicable	Most Organics
Electro-Pure Systems, Inc., Amherst, NY (E02)	Alternating Current Electrocoagulation Technology	James LaDue 716-691-2610 716-691-2613	Randy Parker 513-569-7271	Groundwater, Wastewater, Leachate	Heavy Metals	Petroleum By-products, Coal-Tar Derivatives
Energy and Environmental Engineering, Inc., East Cambridge, MA (E01)	PhotoCAT™ Process	James Porter 617-666-5500	Ronald Lewis 513-569-7856	Groundwater, Wastewater	Not Applicable	Various Organics, PCP, PCBs, Dioxins, Pesticides
Energy and Environmental Research Corporation, Irvine, CA (E03)	Hybrid Fluidized Bed System	Richard Koppang 714-859-8851	Teri Richardson 513-569-7949	Solids, Sludge	Volatile Inorganics	Nonspecific Organics

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APPENDIX IIIc (continued)

Completed Emerging Technology Program Projects as of October 1994

Developer	Technology	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
Montana College of Mineral Science and Technology, Butte, MT (E05)	Campbell Centrifugal Jig	Gordon Ziesing 406-496-4112 406-496-1473	Jack Hubbard 513-569-7507	Soil, Mine Tailings	Heavy Metals	Not Applicable
New Jersey Institute of Technology, Newark, NJ (E03)	GHEA Associates Process	Itzhak Gotlieb 201-596-5862	Annette Gatchett 513-569-7697	Soil, Sludge, Sediment, Water, Industrial Effluent	Heavy Metals	Most Organics, VOCs, SVOCs
PSI Technologies, A Division of Physical Sciences Inc., Andover, MA (E04)	Metals Immobilization and Decontamination of Aggregate Solids	Joseph Morency 508-689-0003	Mark Meckes 513-569-7348	Soil, Sludge, Sediment	Heavy Metals, Volatile Metals	Low Volatile Organics, Organometallics
Pulse Sciences, Inc., San Leandro, CA (E04)	X-Ray Treatment of Aqueous Solutions	Vernon Bailey 510-632-5100	Esperanza Piano Renard 908-321-4355	Water	Not Applicable	VOCs, SVOCs
Purus, Inc.,** San Jose, CA (E04)	Photolytic Oxidation Process	Bart Mass 408-955-1000	Norma Lewis 513-569-7665	Soil, Groundwater	Not Applicable	VOCs
J R. Simplot,** Pocatello, ID (E03)	The SABRE™ Process	Russell Kaake 208-234-5367	Wendy Davis-Hoover 513-569-7206	Soil, Sludge	Not Applicable	Nitroaromatics
Trinity Environmental Technologies, Inc., Mound Valley, KS (E03)	PCB- and Organochlorine-Contaminated Soil Detoxification	Duane Koszalka 316-328-3222	Paul dePercin 513-569-7797	Solids, Sludge	Not Applicable	PCBs, PCP, and Other Chlorinated Hydrocarbon Compounds
University of Washington, Seattle, WA (E02)	Adsorptive Filtration	Mark Benjamin 206-543-7645	Norma Lewis 513-569-7665	Aqueous Waste Streams	Metals, Other Nonspecific Inorganics	Not Applicable
Vortec Corporation,** Collegeville, PA (E04)	Oxidation and Vitrification Process	James Hnat 610-489-2255	Teri Richardson 513-569-7949	Soil, Sludge, Sediment, Mill Tailings	Metals, Other Nonspecific Inorganics	Nonspecific Organics
Wastewater Technology Centre,** Burlington, Ontario, Canada (E02)	Cross-Flow Pervaporation System	Rob Booth 905-336-4689 R. Philip Canning 905-639-6320	John Martin 513-569-7758	Groundwater, Leachate, Wastewater	Not Applicable	VOCs, Solvents, Petroleum Hydrocarbons

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APPENDIX IIIc (continued)

Completed Emerging Technology Program Projects as of October 1994

Developer	Technology	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
Ferro Corporation, Independence, OH (E03)	Waste Vitrification Through Electric Melting	Emilio Spinosa 216-641-8580	Randy Parker 513-569-7271	Soil, Sludge, Sediment	Nonspecific Inorganics	Nonspecific Organics
Hazardous Substance Management Research Center at New Jersey Institute of Technology, Newark, NJ (E04)	Pneumatic Fracturing/ Bioremedation	John Schuring 201-596-5849	Uwe Frank 908-321-6626	Soil	Not Applicable	Petroluem Hydrocarbons, Benzene, Toluene, Xylene
Institute of Gas Technology,** Des Plaines, IL (E04)	Chemical and Biological Treatment	Robert Kelley 708-768-0722	Ronald Lewis 513-569-7856	Soil, Sludge, Groundwater, Surface Water	Not Applicable	Most Organics
Institute of Gas Technology,** Des Plaines, IL (E03)	Fluid Extraction - Biological Degradation Process	Robert Paterek 708-768-0500	Annette Gatchett 513-569-7697	Soil, Solids	Not Applicable	Hydrocarbons, Nonhalogenated Aliphatic Hydrocarbons, PAHs
IT Corporation, Knoxville, TN (E02)	Batch Steam Distillation and Metal Extraction	Robert Fox 615-690-3211	Ronald Lewis 513-569-7856	Soil, Sludge	Heavy Metals, Nonspecific Inorganics	Nonspecific Organics
IT Corporation, Knoxville, TN (E03)	Photolytic and Biological Soil Detoxification	Robert Fox 615-690-3211	Randy Parker 513-569-7271	Soil	Not Applicable	PCBs, Dioxins, PAHs, Other Nonspecific Organics
Matrix Photocatalytic Inc. (formerly Nutech Environmental),** London, Ontario, Canada (E05)	Photocatalytic Water Treatment	Bob Henderson 519-660-8669	John Ireland 513-569-7413	Wastewater, Groundwater, Process Water	Nonspecific Inorganics	PCBs, PCDDs, PCDFs, Chlorinated Alkenes, Chlorinated Phenols
Membrane Technology and Research, Inc., Menlo Park, CA (E02)	VaporSep™ Membrane Process	David Dortmundt or Marc Jacobs 415-328-2228	Paul dePercin 513-569-7797	Gaseous Waste Streams	Not Applicable	Halogenated and Nonhalogenated Organics
Montana College of Mineral Science & Technology, Butte, MT (E03)	Air-Sparged Hydrocyclone	Theodore Jordan 406-496-4112 406-496-1473	Euguene Harris 513-569-7862	Aqueous Solutions	Low-Concentration Metals	Not Applicable

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